

Data Analysis for Bo VST

Signal Processing and Deconvolution

Talk 3 of 6

Ben Jones

Global strategies

- We have two different analysis pathways, to extract the underlying time constants.
 - 1) Measure average impulse (single PE) response. Measure average signal pulse. Deconvolve using fourier methods. Extract time constants with simple fits.
 - 2) Forward fit – make a hypothesis, convolve with impulse response, minimize chi2 to find best fit point
- In this talk I describe method 1, which resembles the analysis performed by WArP.
- Christie will describe method 2 in the next talk.

Impulse response of system is measured with a pulsed LED.

We re-measure this impulse response between every pair of measurements to compensate for pulse shape drift.

Response function is averaged over 10,000 samples using a visible LED. Ringing is clearly visible on average pulse.

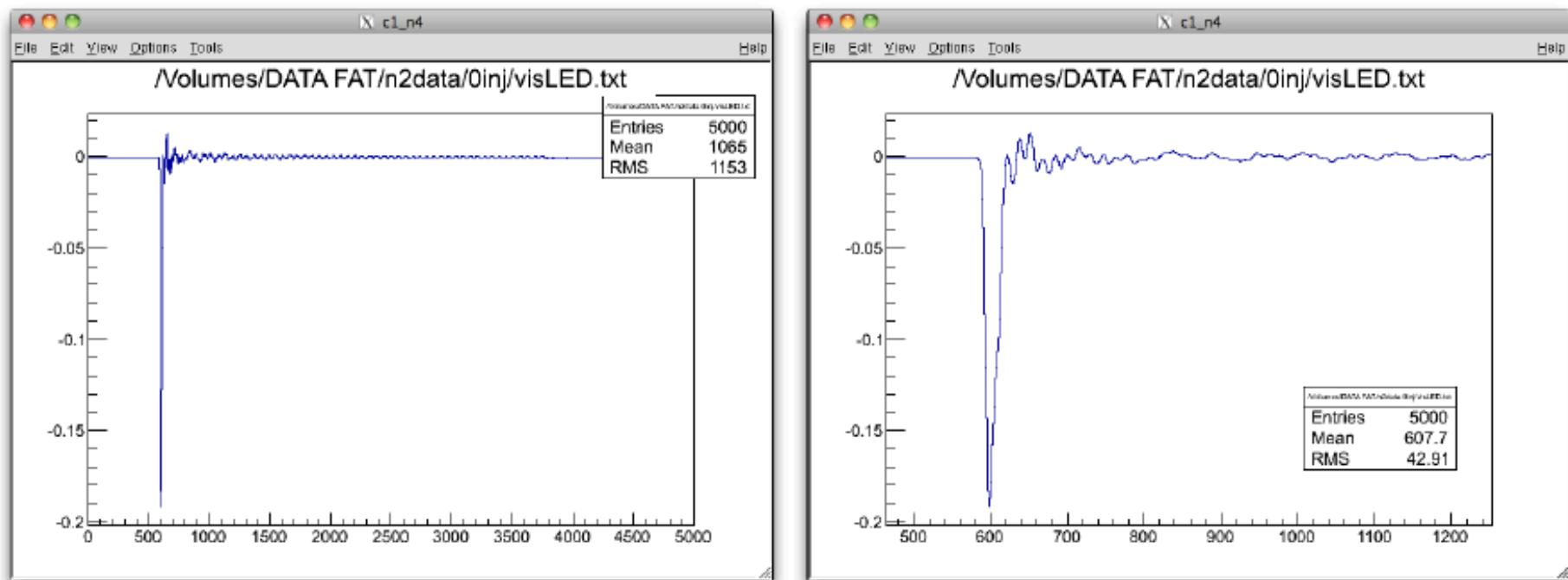


Figure 1: Single PE pulse shape, generated with an LED

Next we transform into fourier space. This will be our deconvolution kernel.

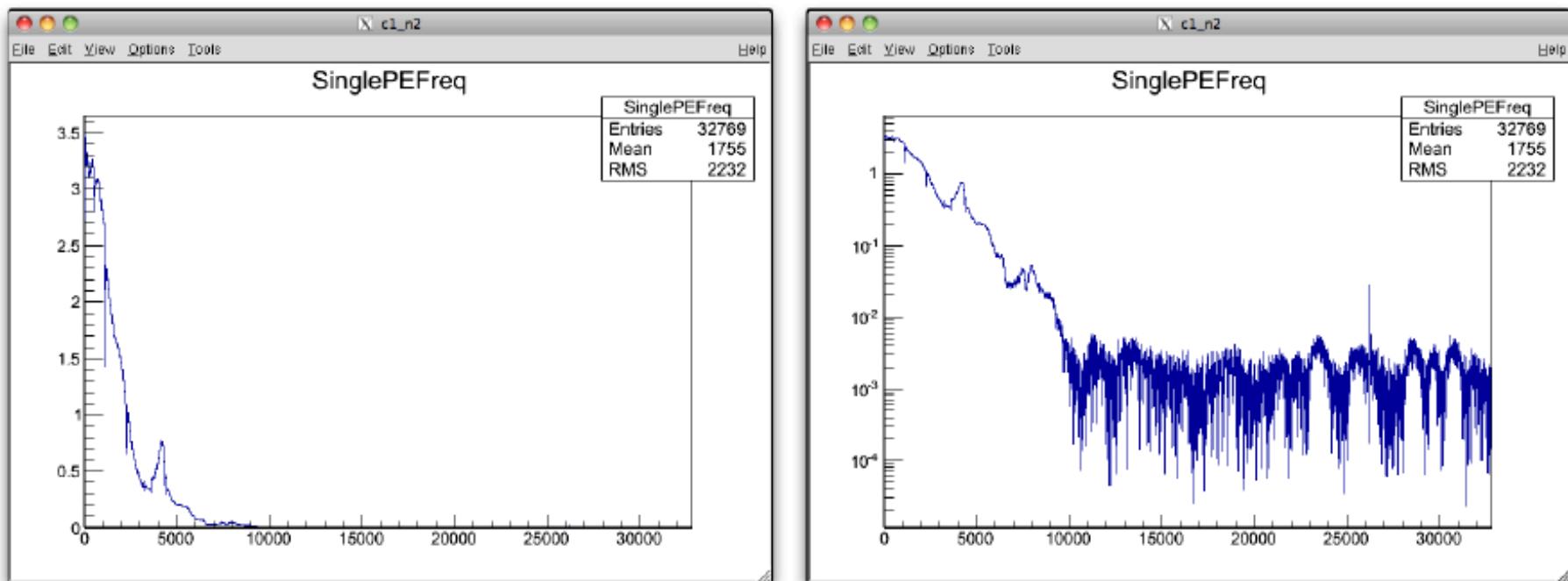


Figure 2: Single spike LED pulses, in fourier space

Next we transform into fourier space. This will be our deconvolution kernel.

A few notable features:

Very sharp poles in frequency response – we suspect sampling mechanism of scope

Some type of resonance feature – we suspect base or splitter

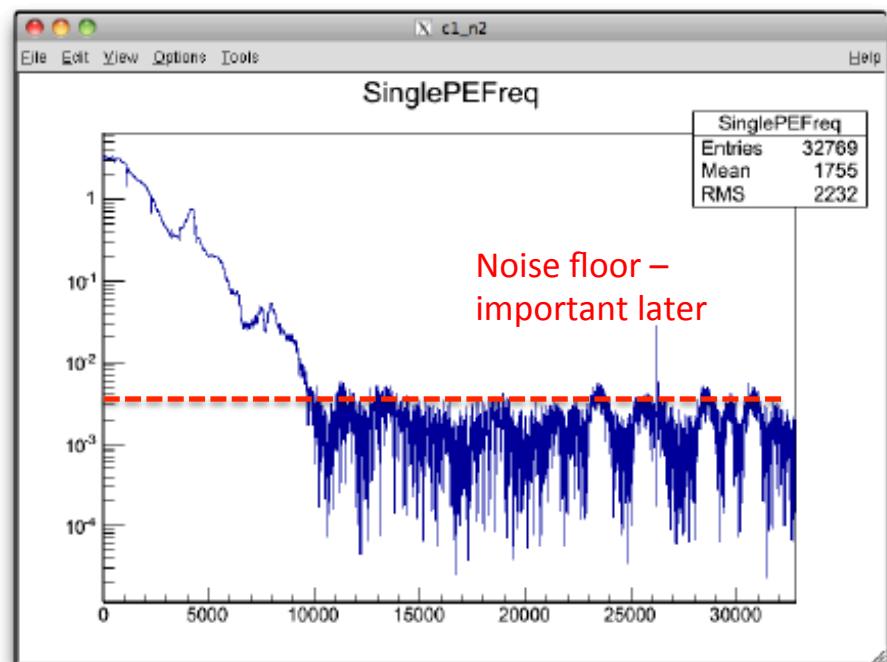
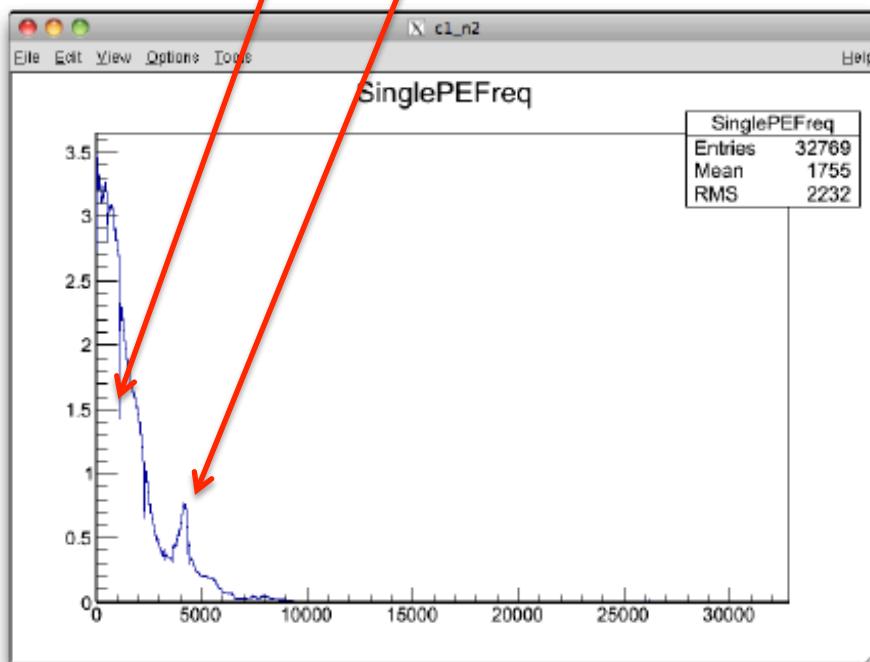


Figure 2: Single spike LED pulses, in fourier space

Stability of Impulse Response

- It is important to monitor any drift in the impulse response.
- We re-measure with the LED between every injection sample.
We make two cross-checks between each sample:
 - PMT gain drift (known effect from Teppei's work). Look at area of average pulse to monitor PMT gain
 - Impulse shape drift. This is what we really care about.
- Shape is measured by calculating Pearson's correlation coefficient for normalized average pulses.
- Each bin is considered one sample. We look at how the value per bin is correlated. 1 = perfect correlation.

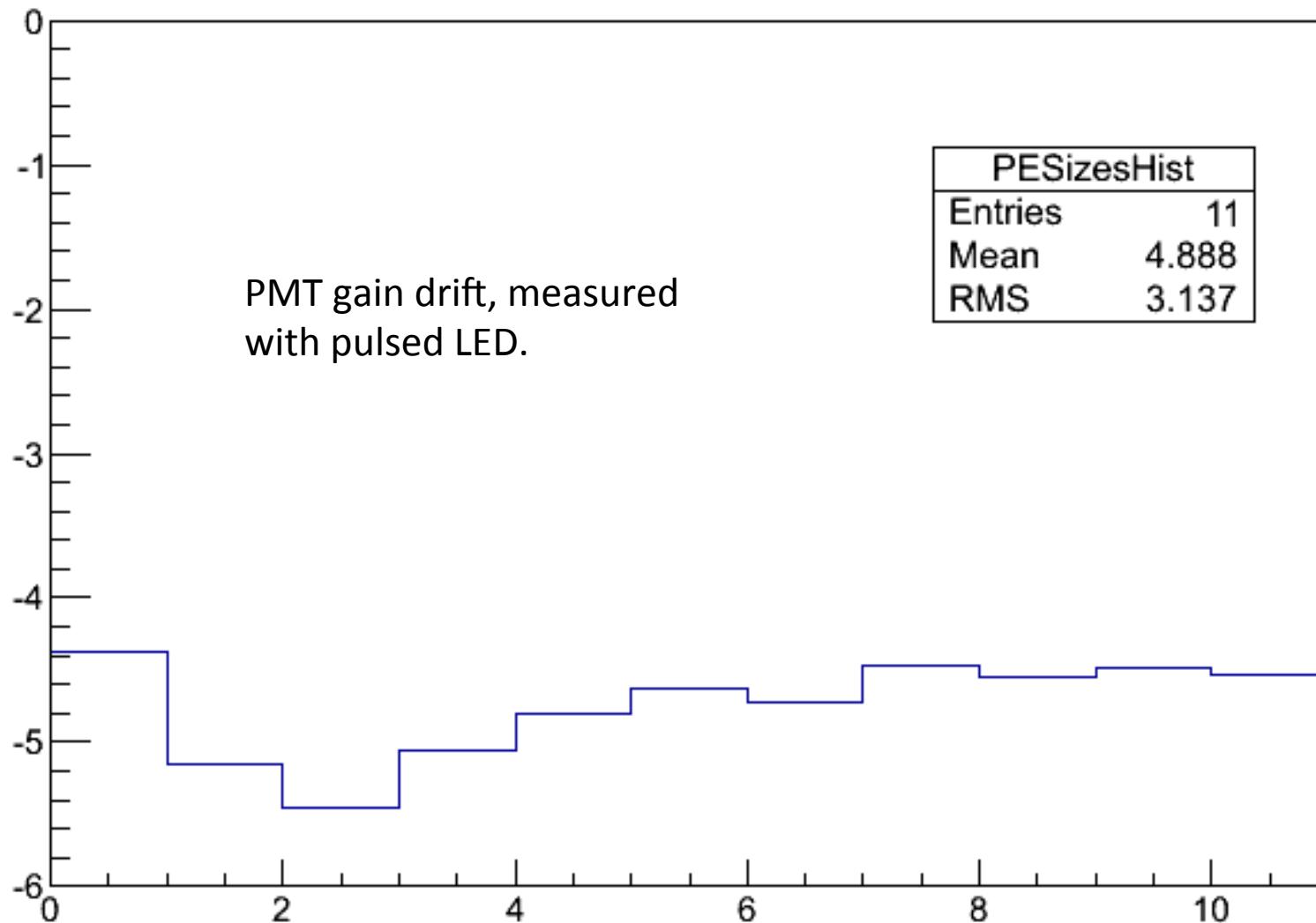
$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^n (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^n (Y_i - \bar{Y})^2}}$$



X c1_n2

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

PESizesHist





Next slide
(don't panic)

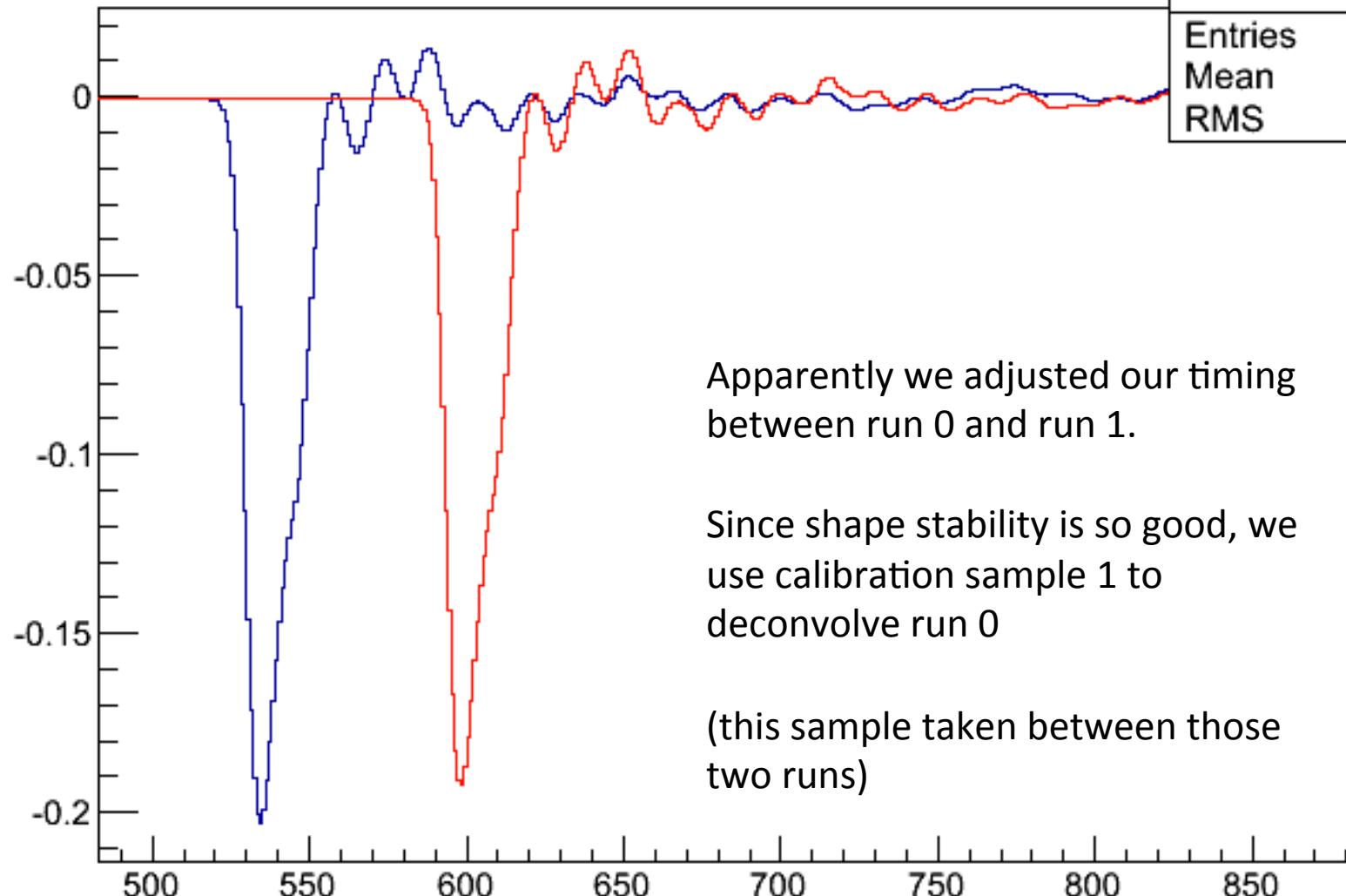
CorrHist

Pulse shape is very stable for these

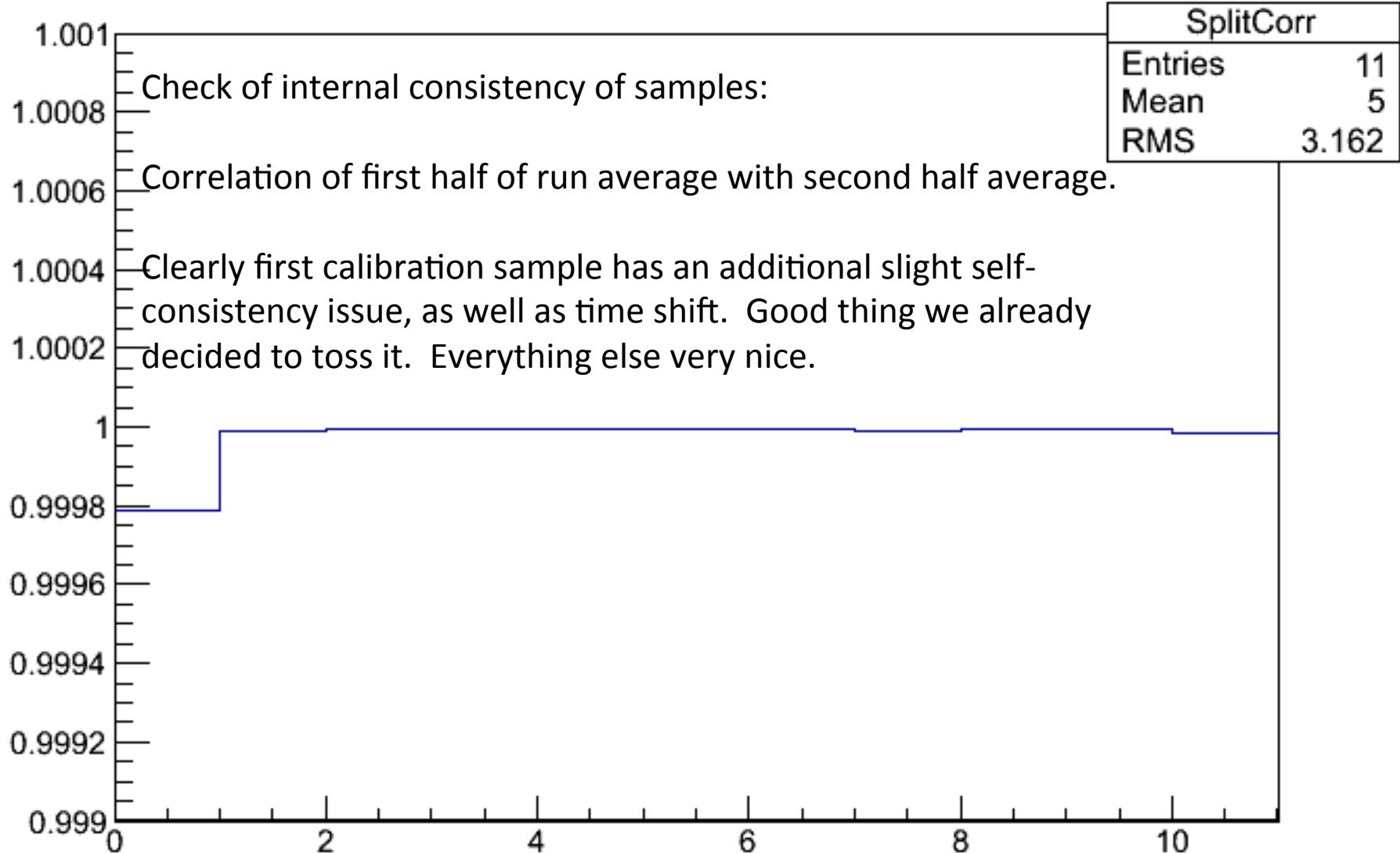




..../BoLN2Dataset/n2data/1inj/VisLED.txt



Split sample correlation



Typical signal pulse we want to deconvolve
(all preliminaries shown here are 0inj cosmics)

Note : PMT undershoot and its biasing effect
on time constant very apparent here!

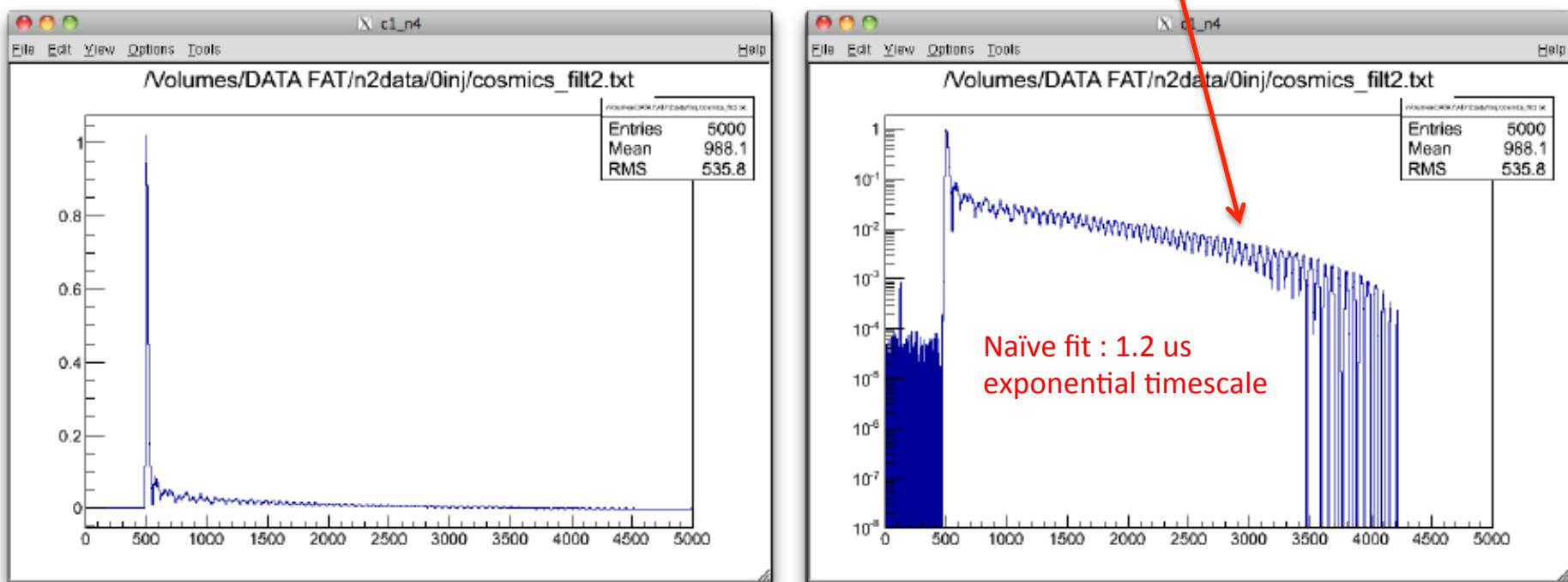


Figure 3: Averaged pulse from cosmic ray scintillation in LAr

So to deconvolve, we divide the signal response by the impulse response in frequency space, right?

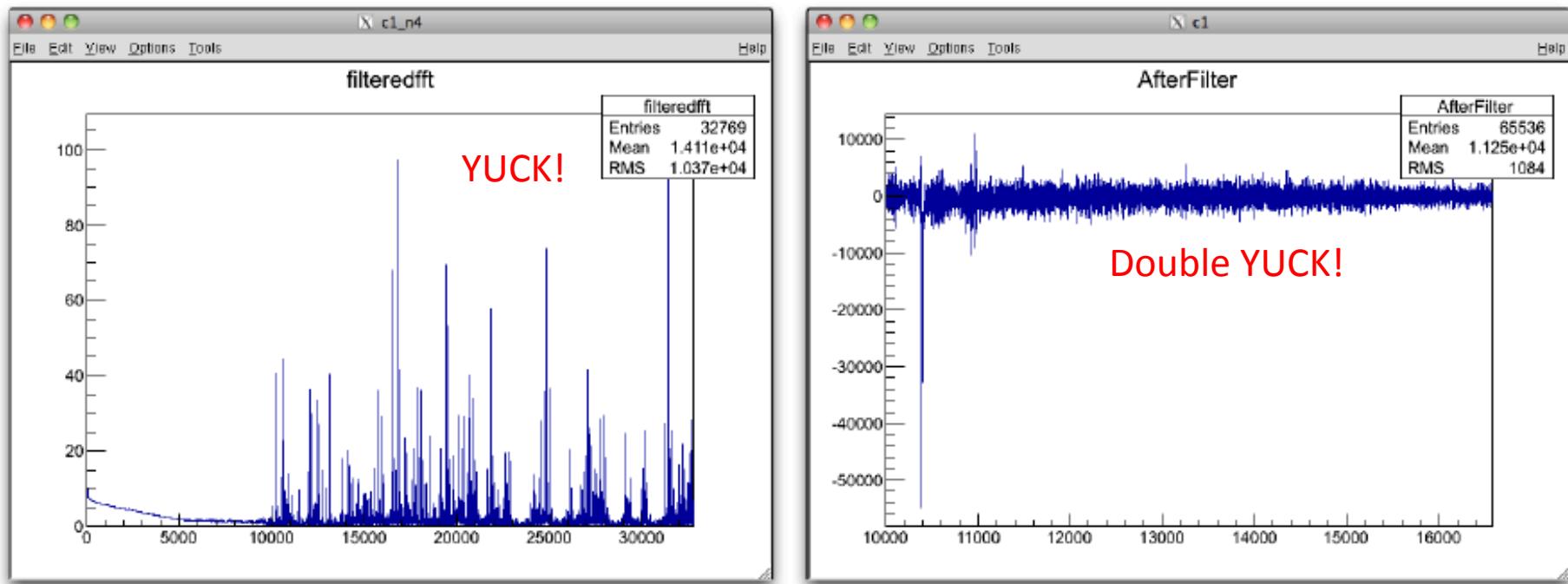
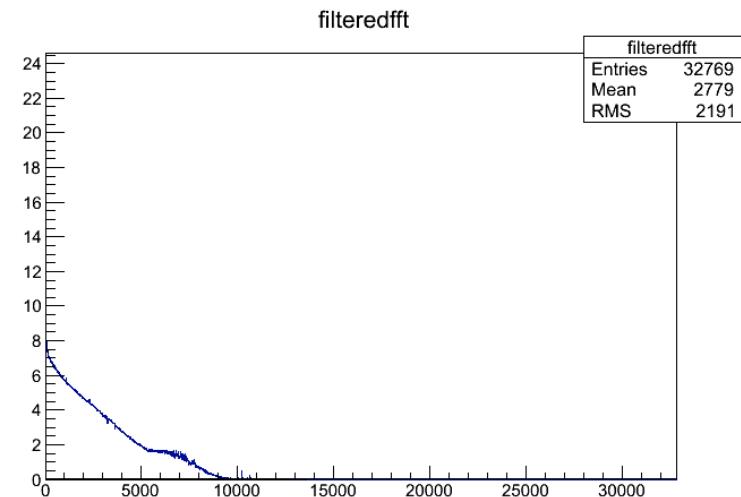
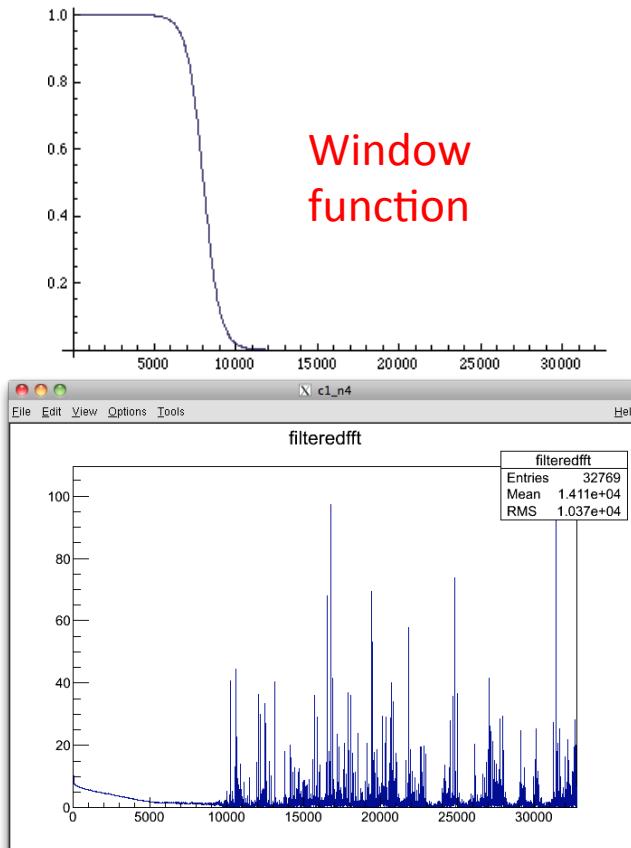


Figure 4: Deconvolved singal in fourier and real space

In the high frequency range all we have is random white noise on the single PE pulse, and random white noise on the signal.

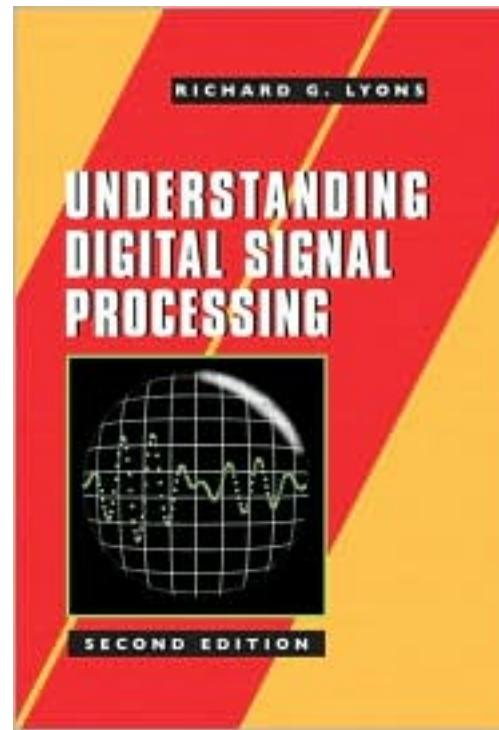
We just gave ourselves random noise squared. Solution : low pass filter * to clean up the pulse



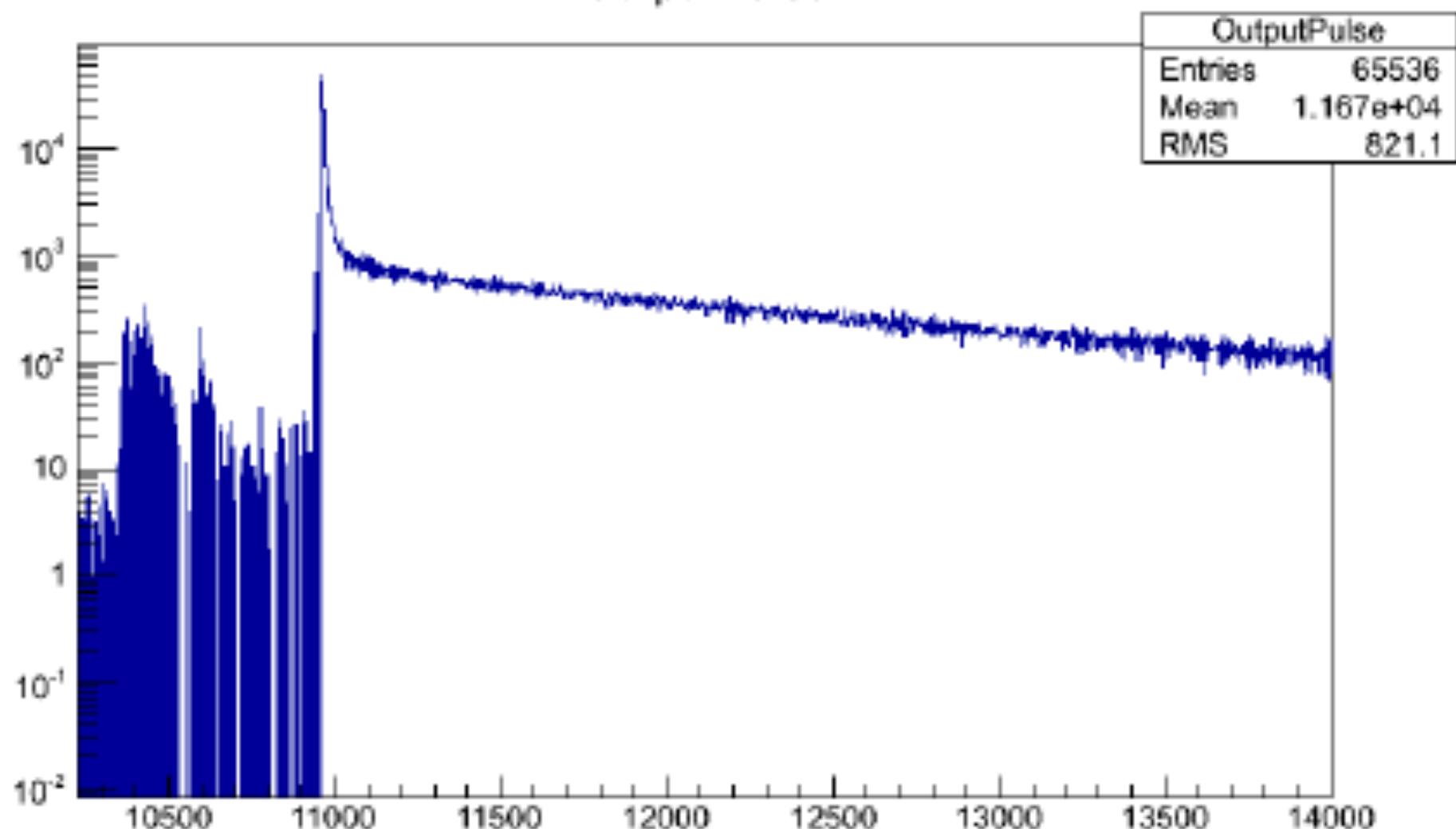
* Weiner filter tuned on measured noise floor, followed by sigmoid window function. This allows for a higher cutoff point, and is the formally optimal filtering method. Thanks to **Warren Schapert** for advising us on these procedures!

More technical details:

- Following standard methods described this book we:
 - Pad with zeroes to $>2x$ window size to prevent frequency space wraparound
 - Apply a smooth window function (double sigmoid) to prevent sharp jumps at edge of sample space. This reduces high frequency artifacts from steps.
 - Remove DC baseline from both signal and kernel measured using presamples.



OutputPulse

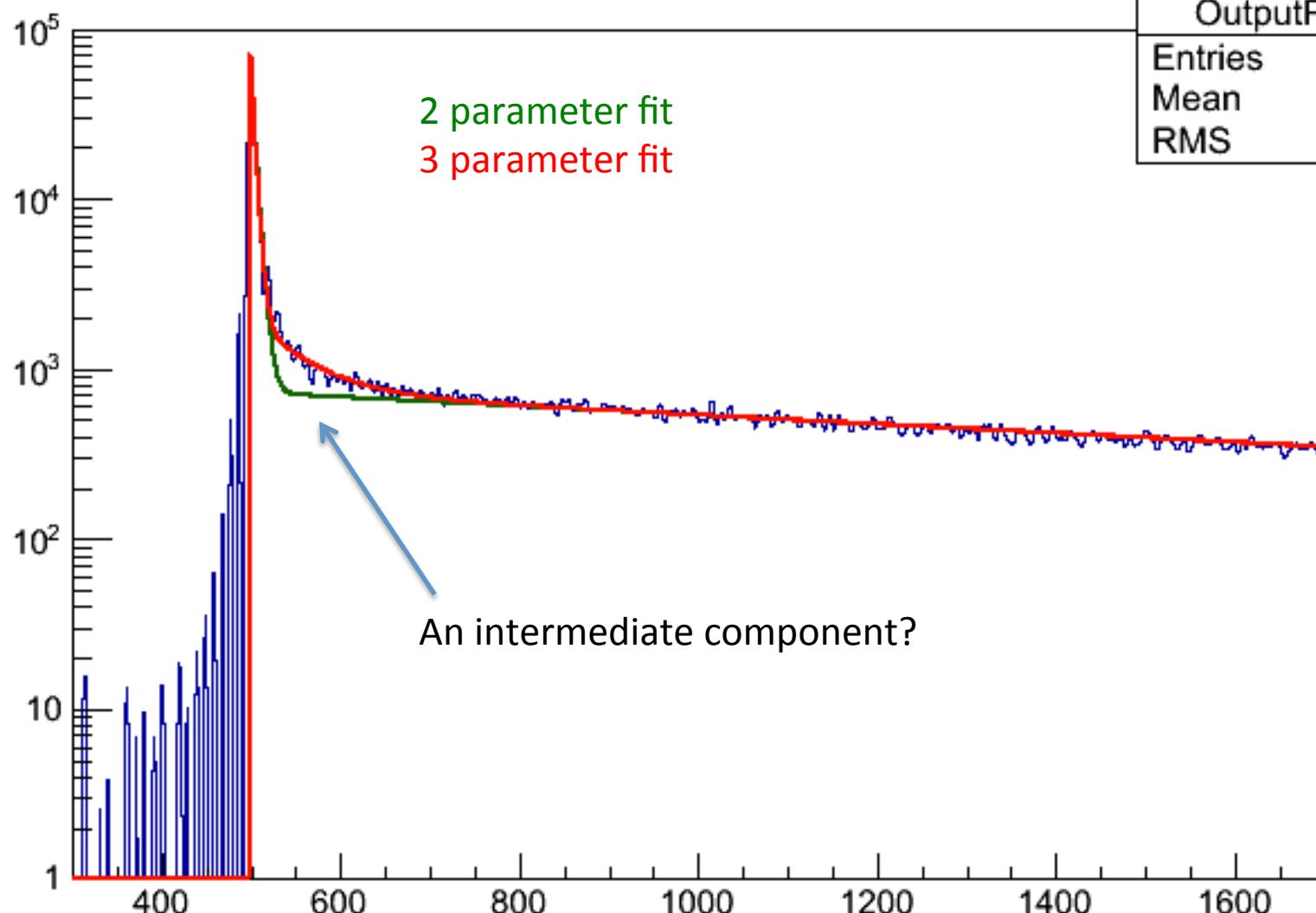


Much nicer!



OutputPulse

OutputPulse	
Entries	5000
Mean	794.7
RMS	359.8

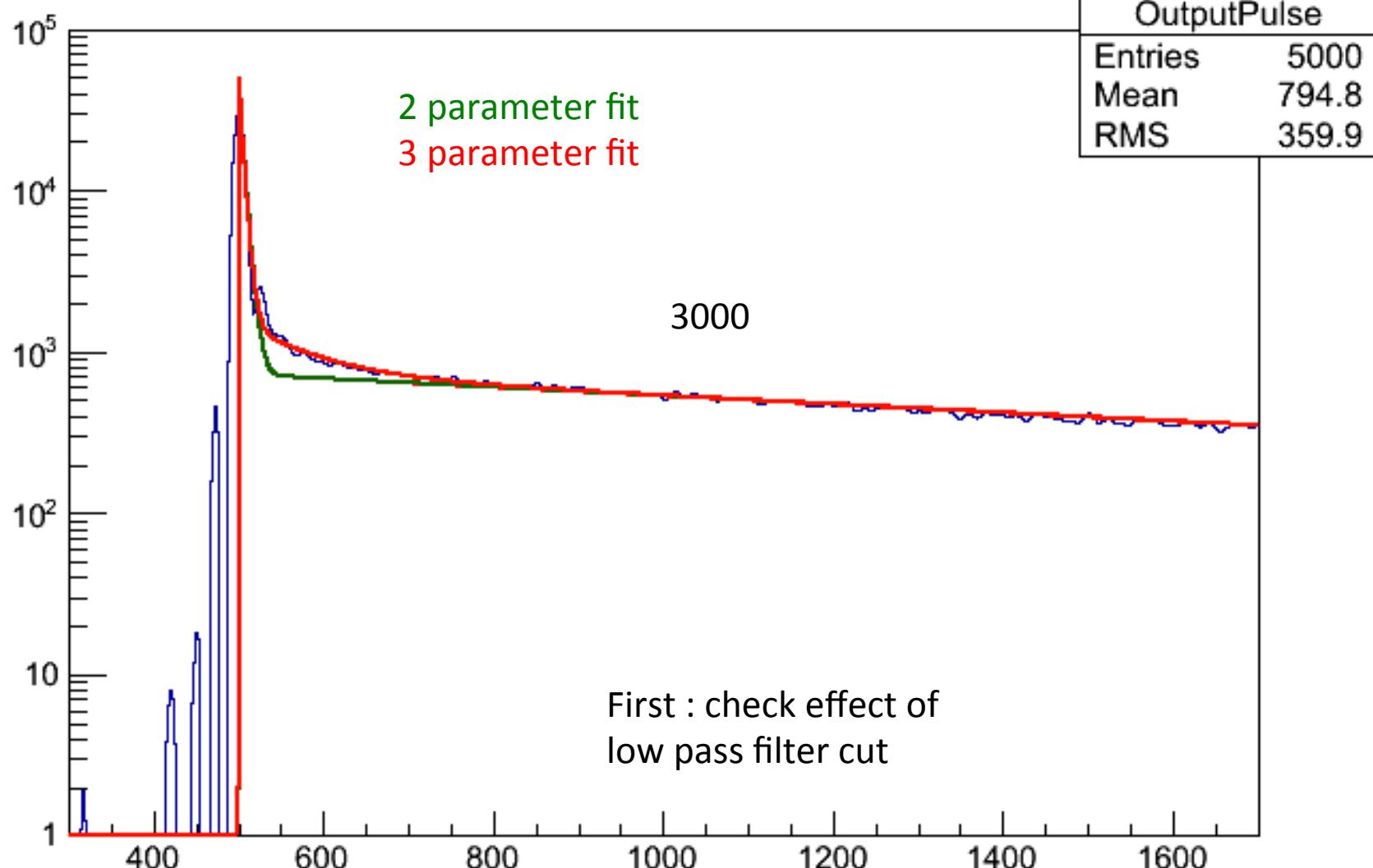


But, not so hasty...

- We know from expert consultations that there is in general no frequency space treatment which does not bias an extracted signal in time space.
- Low pass filters inject time ripples. Steadily varying filters designed to prevent time ringing will change exponential frequency spectrum and change its shape.
- How do we know whether what we have extracted is representative of the real distribution?
- First we test whether varying the frequency cut changes the fit...



OutputPulse

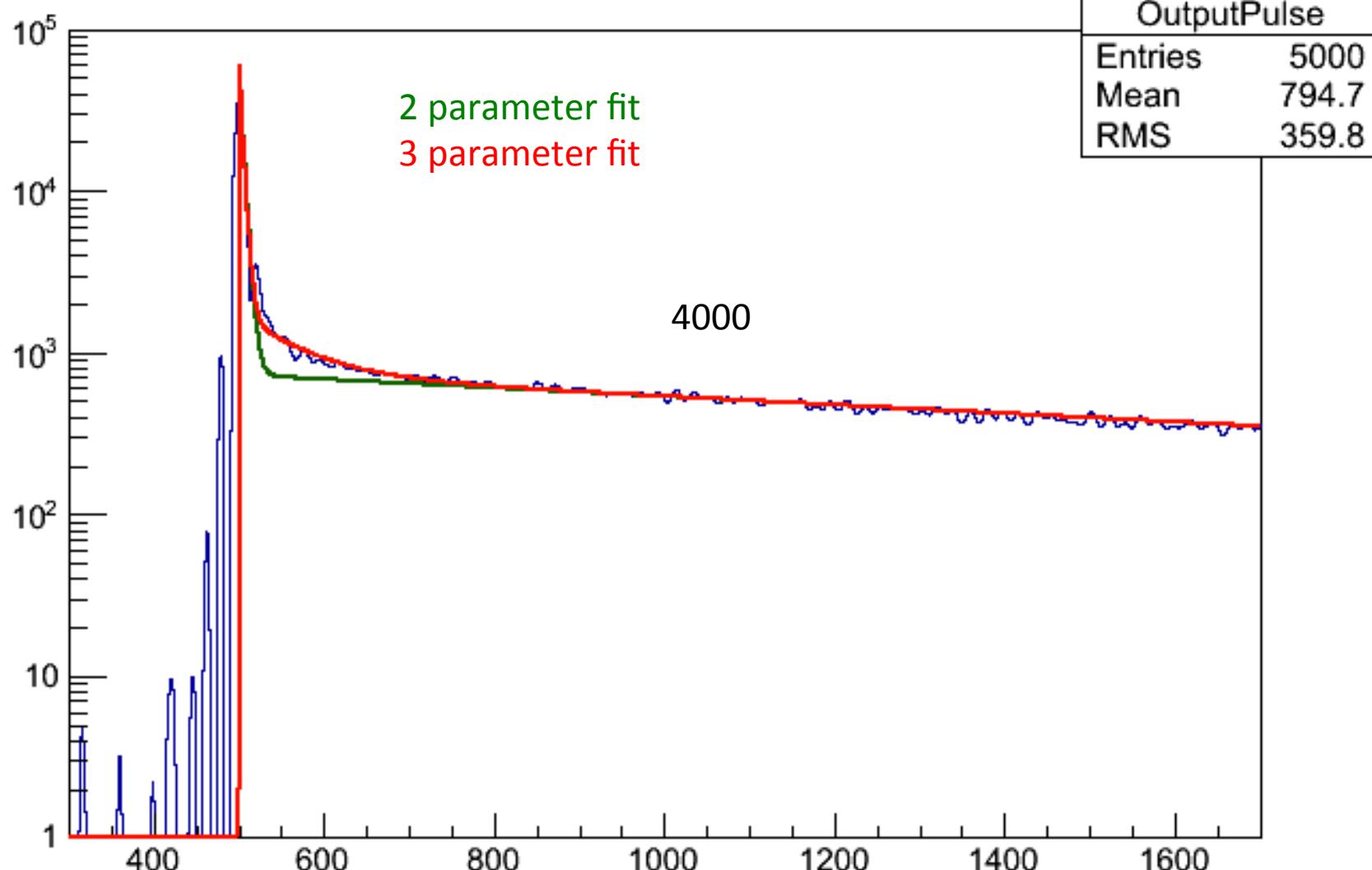




X c1_n5

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

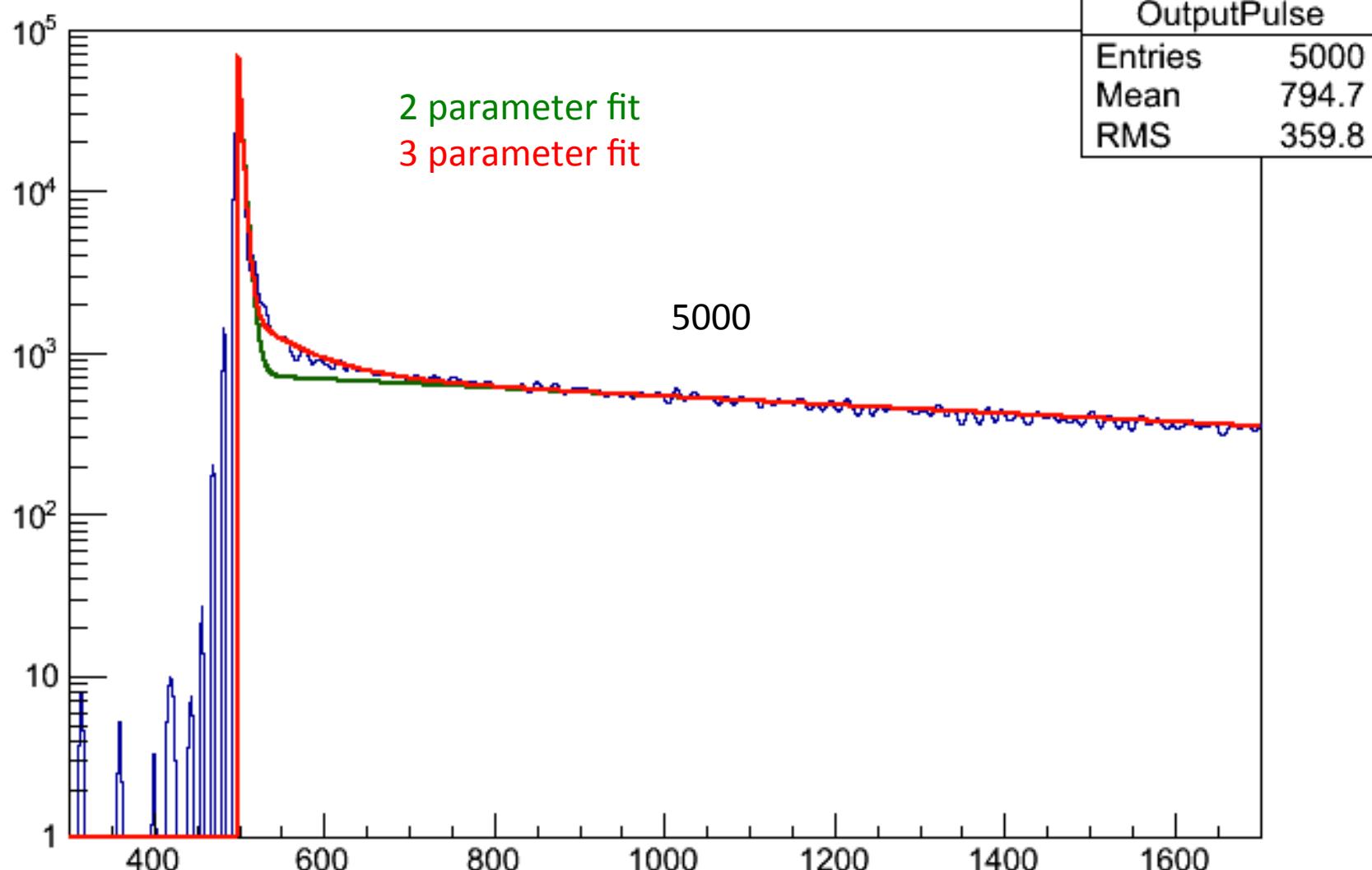




X c1_n5

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

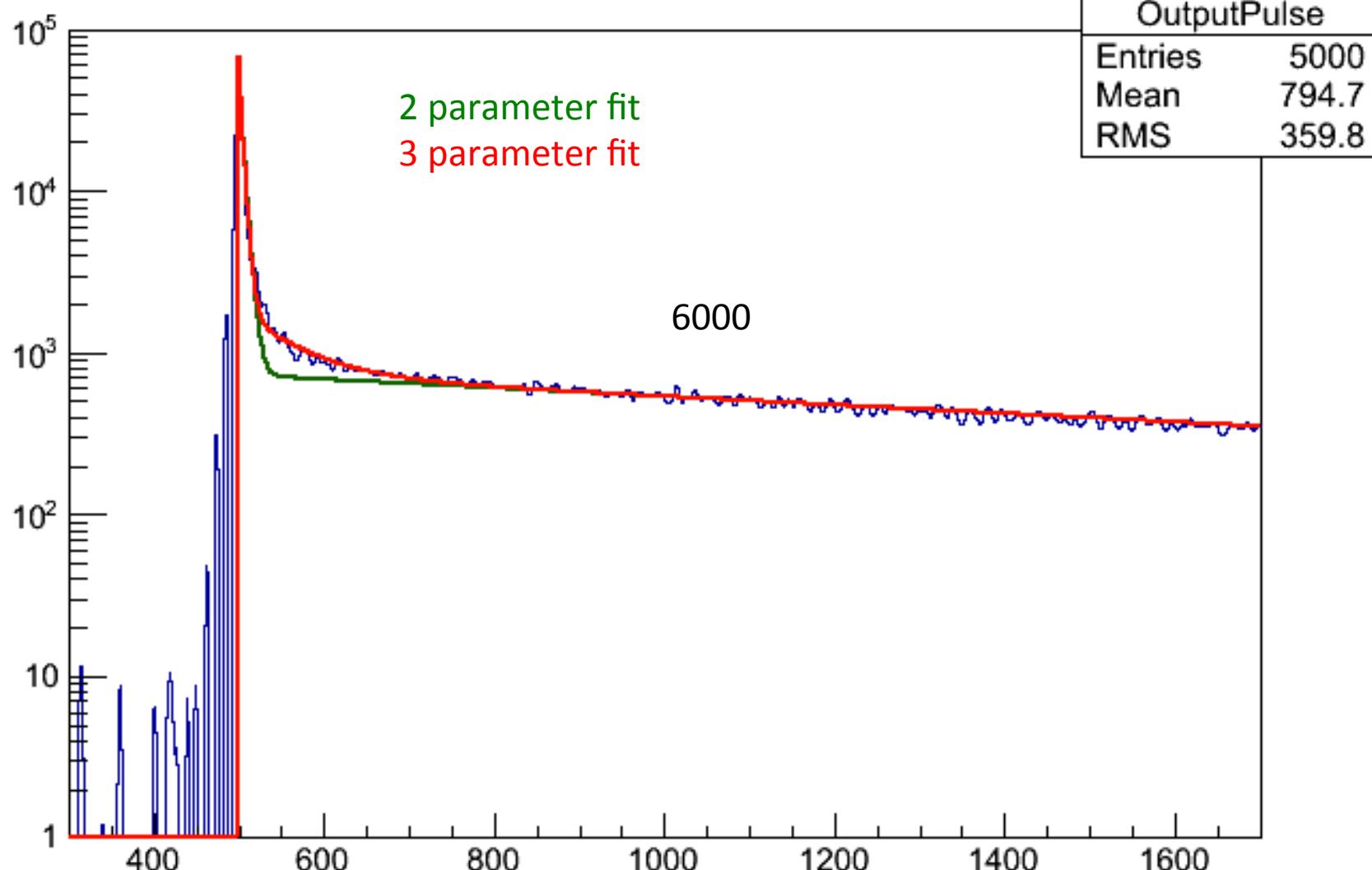




X c1_n5

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

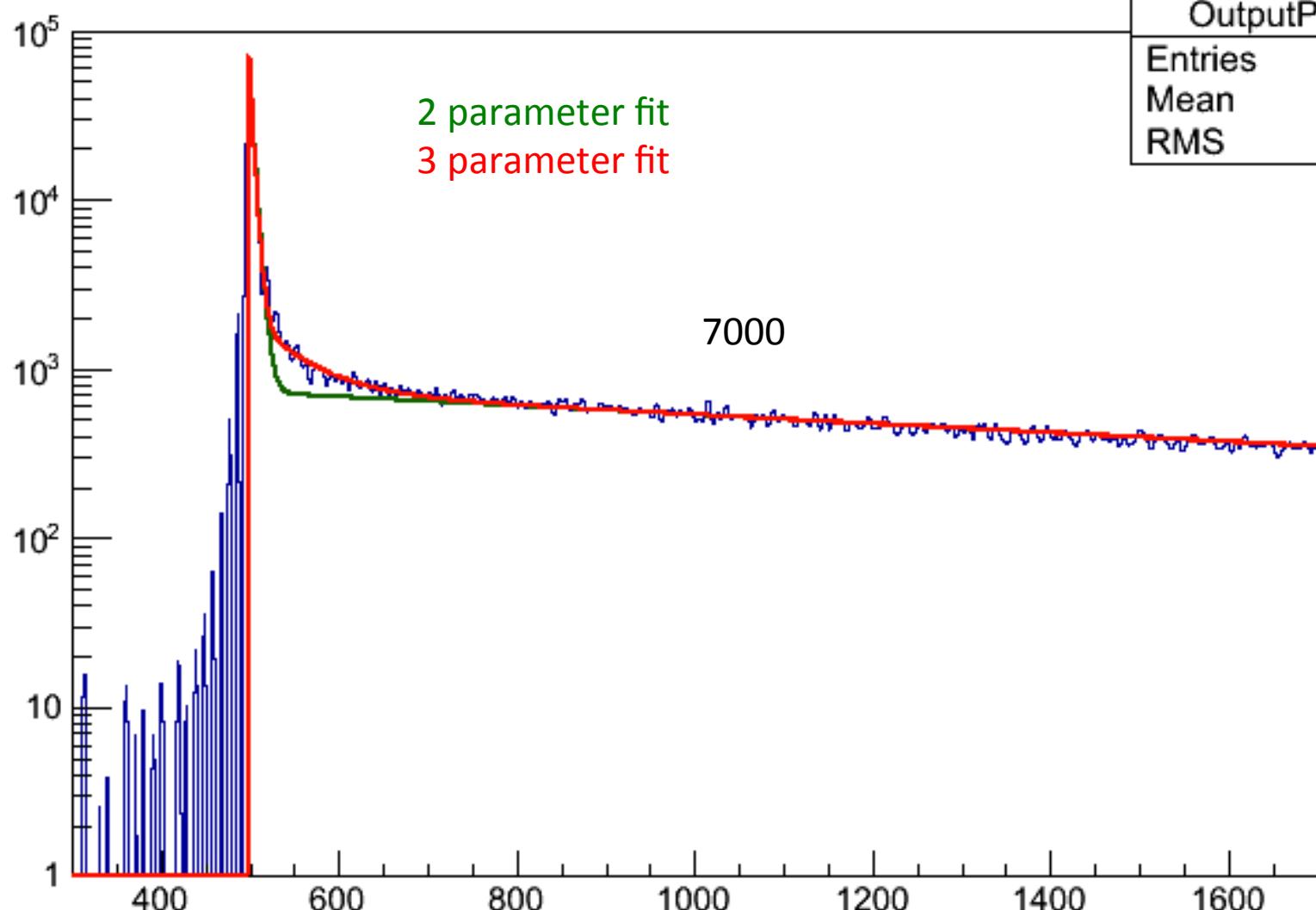




X c1_n5

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

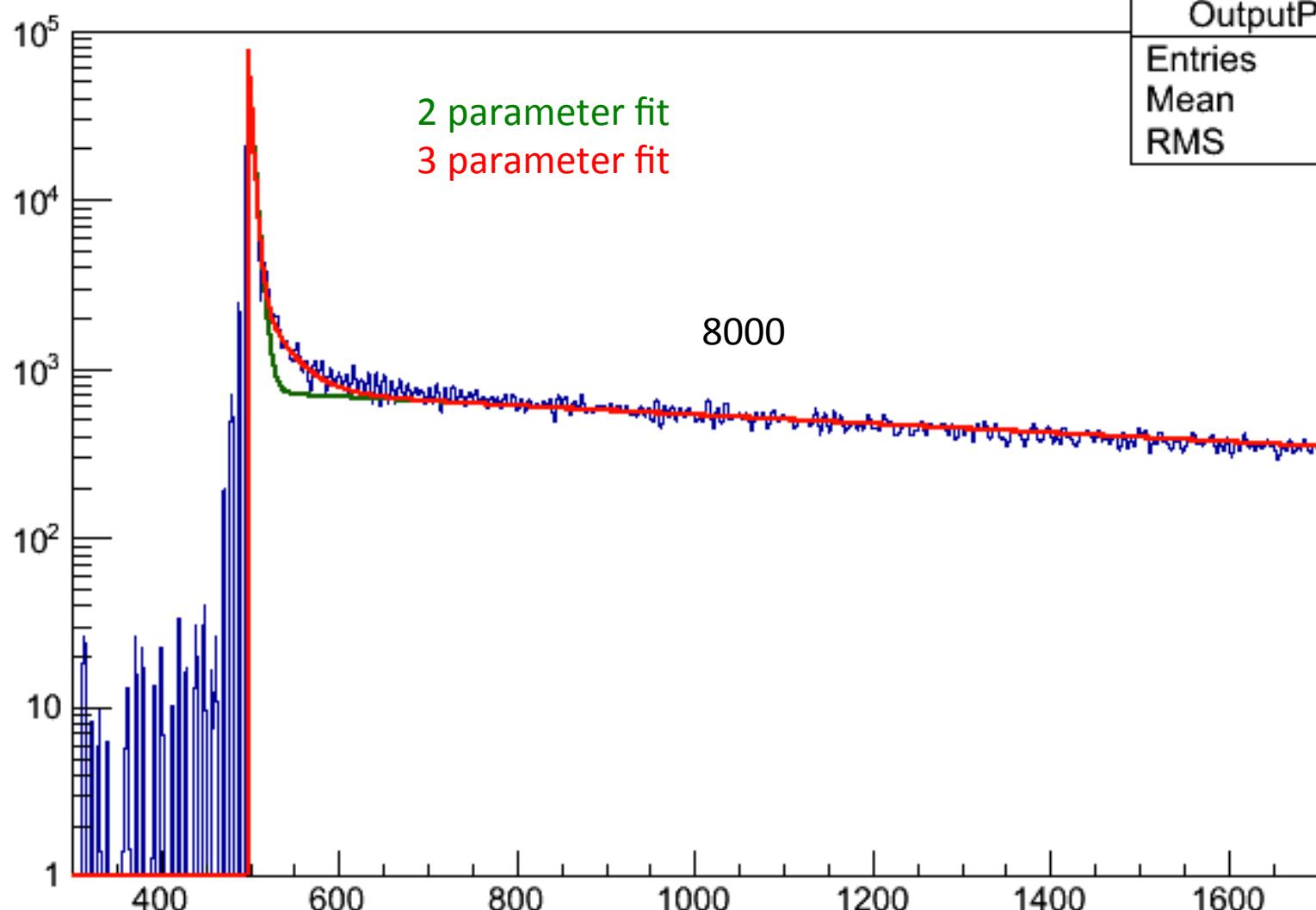




X c1_n5

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

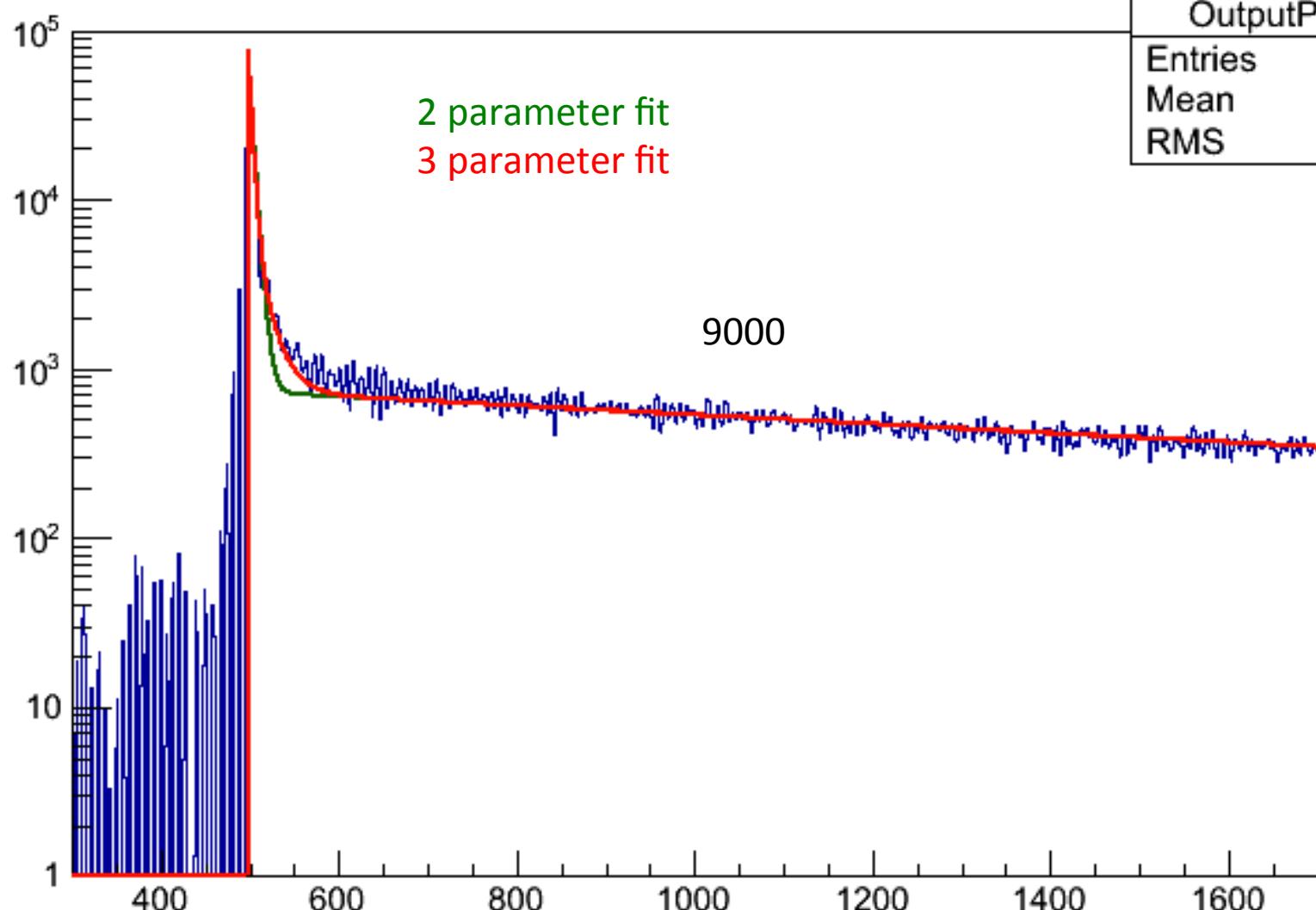




X c1_n5

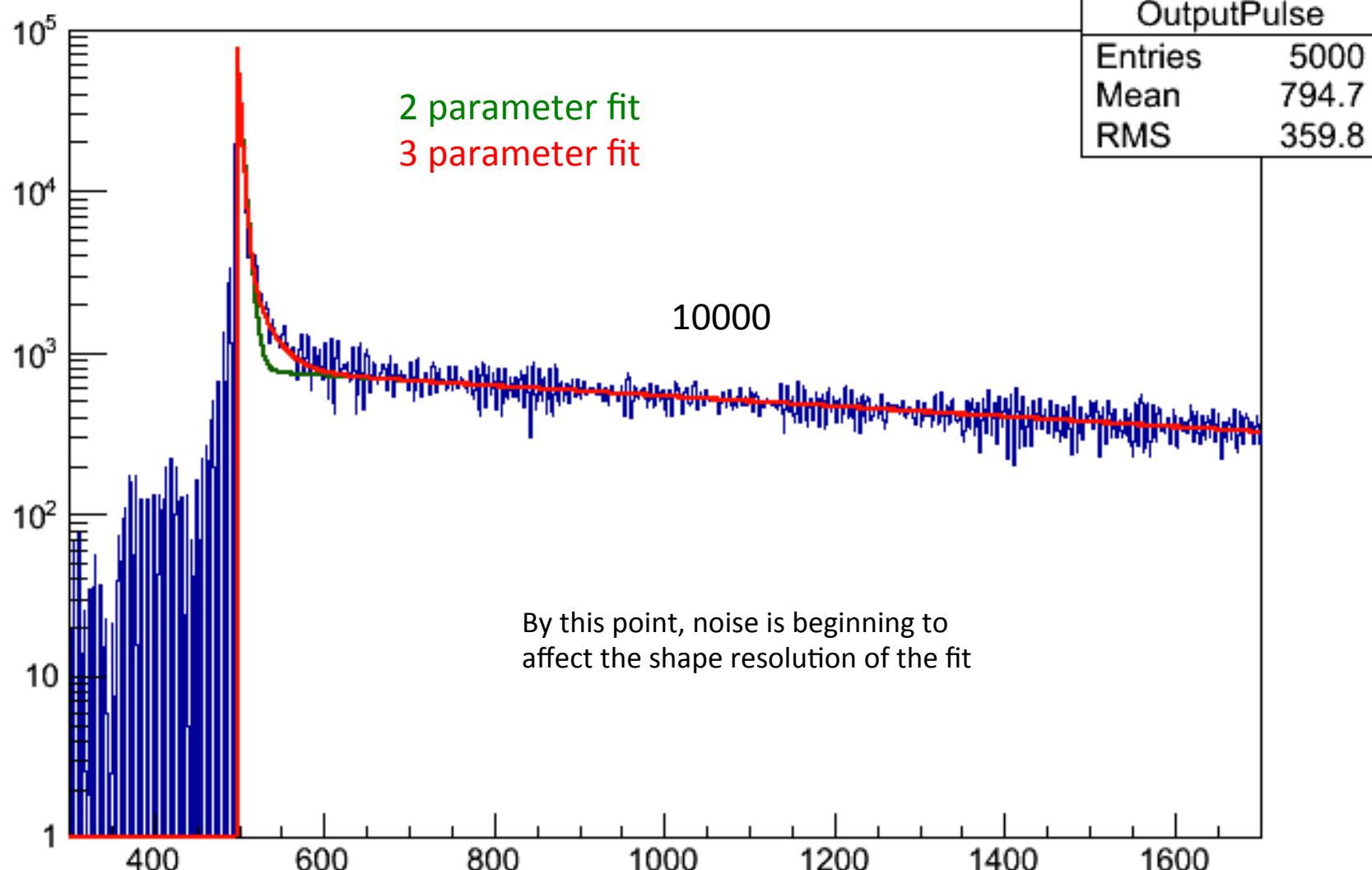
[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

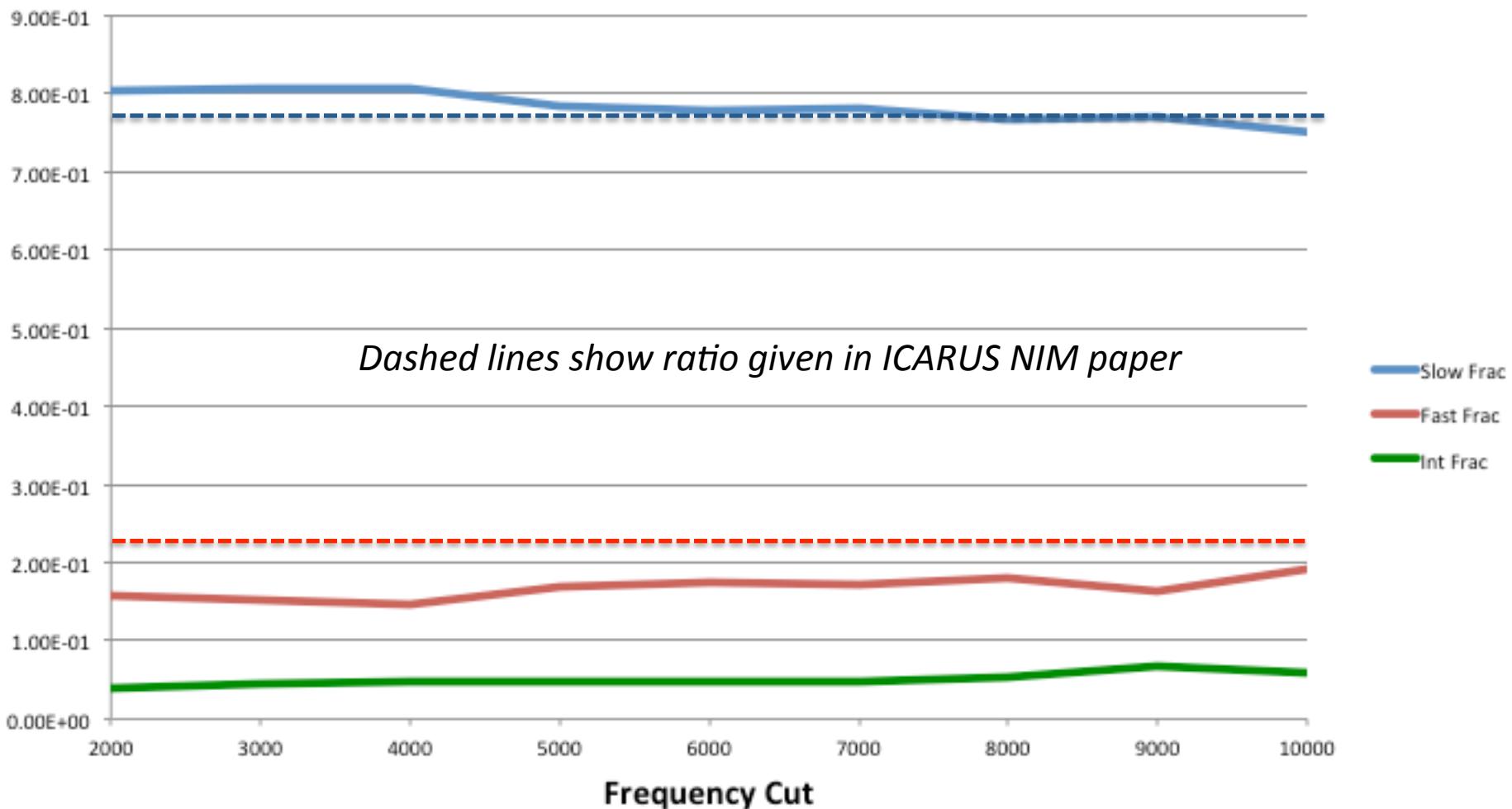




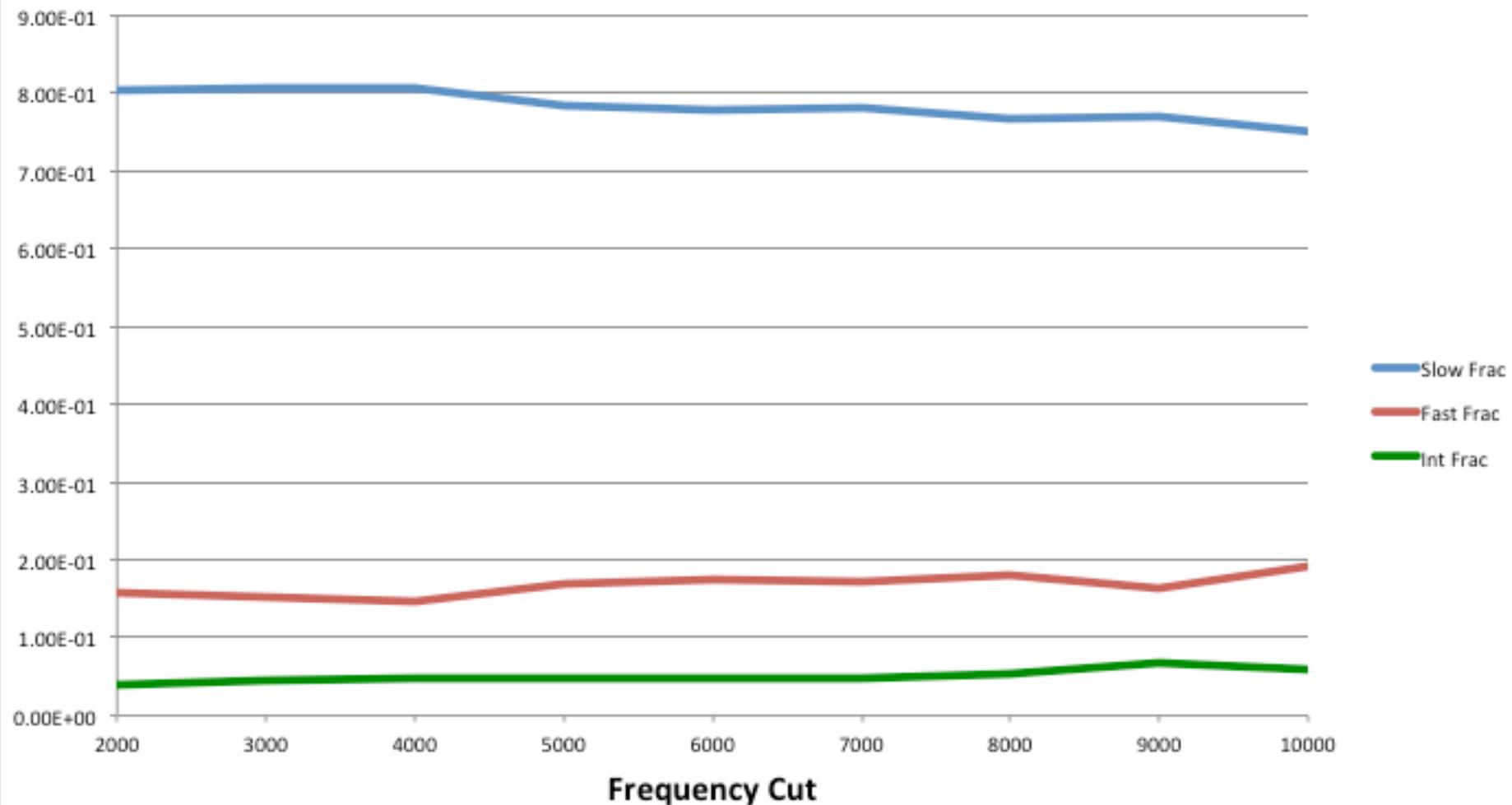
OutputPulse

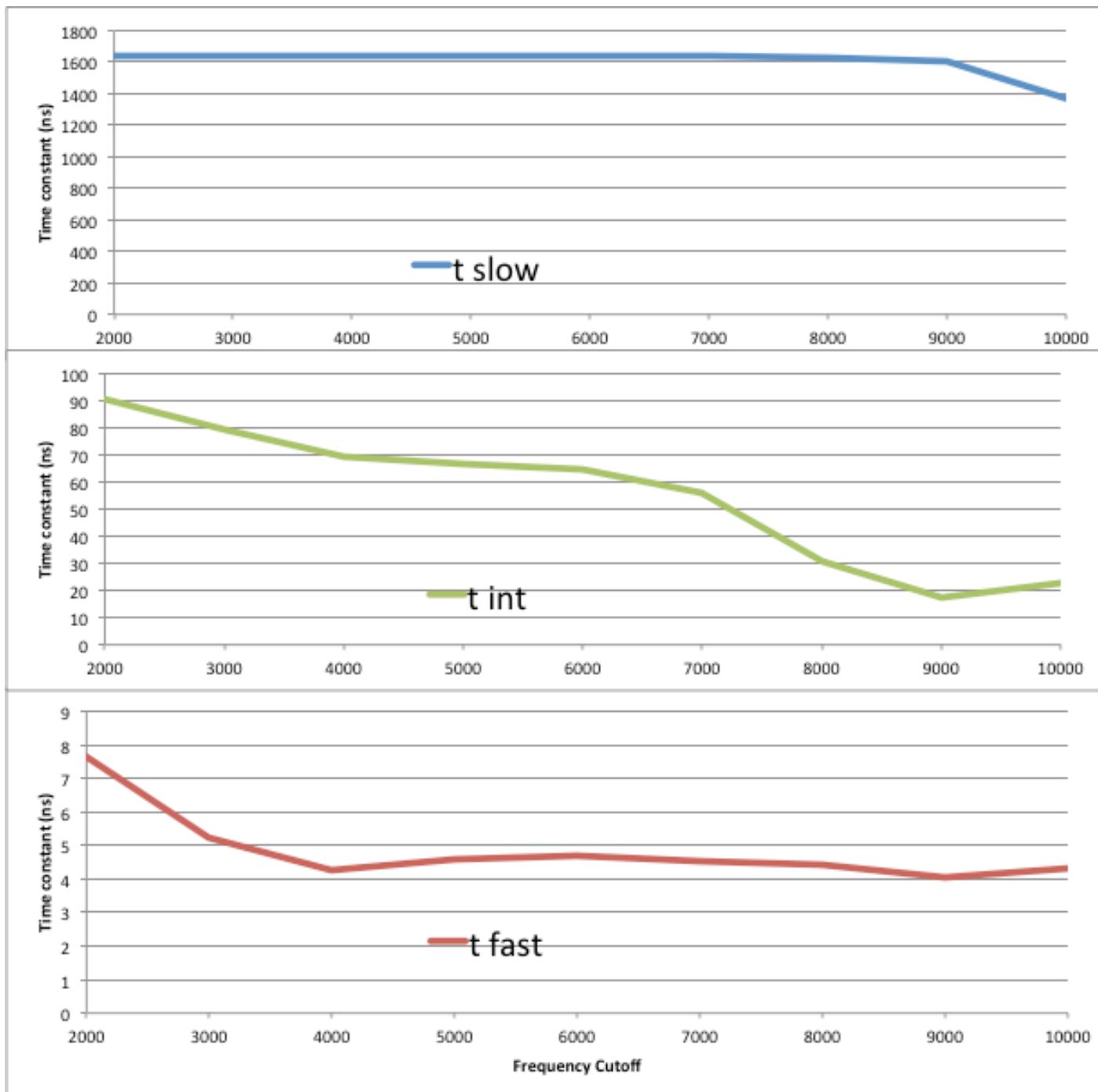


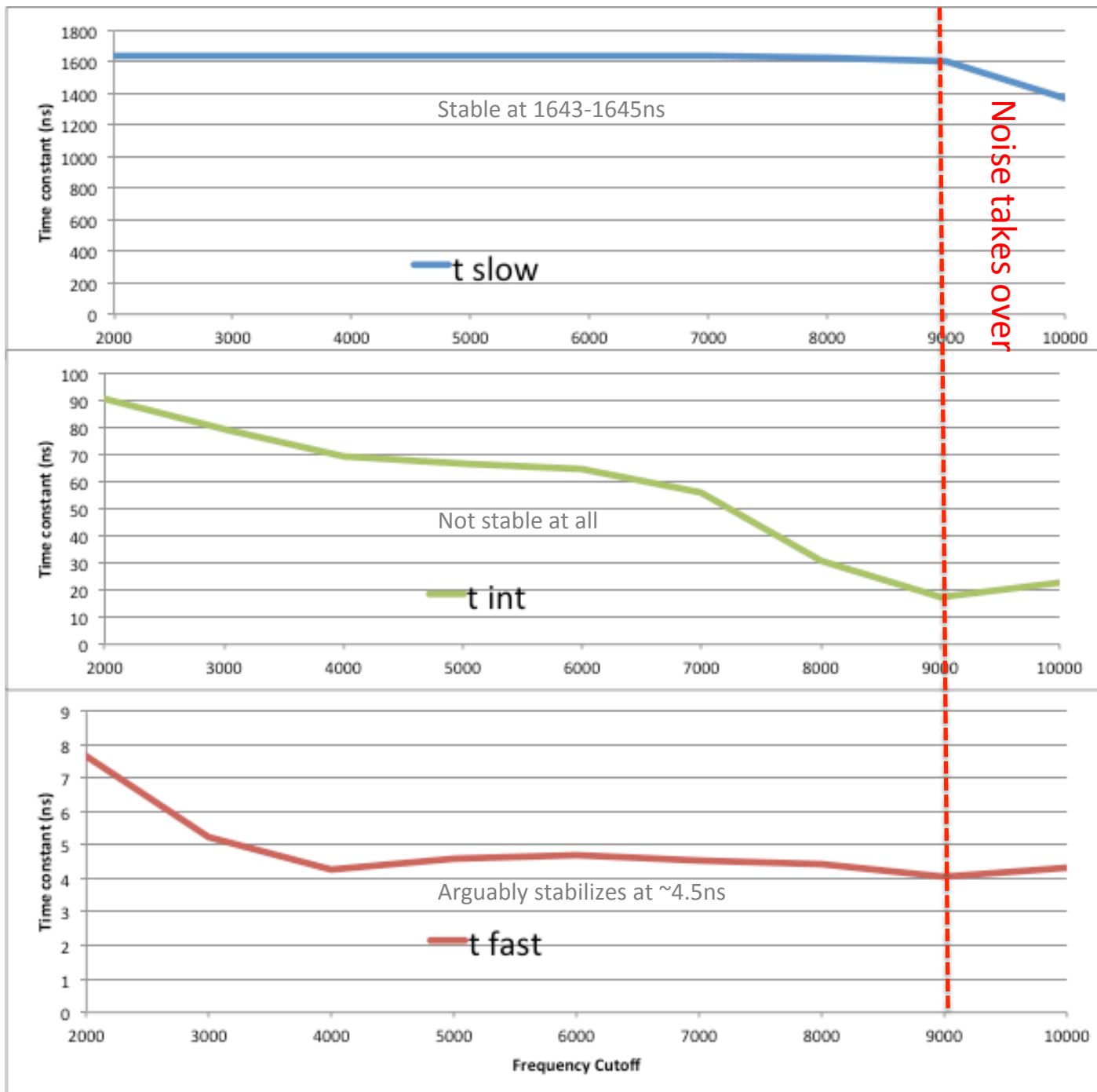
Fraction of Light with each Time Constant



Fraction of Light with each Time Constant

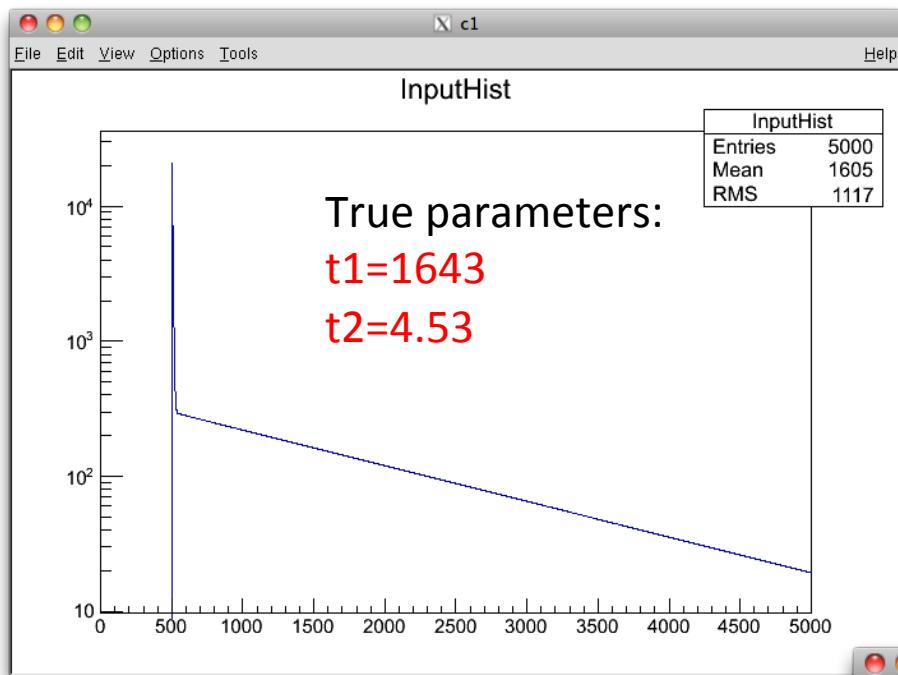






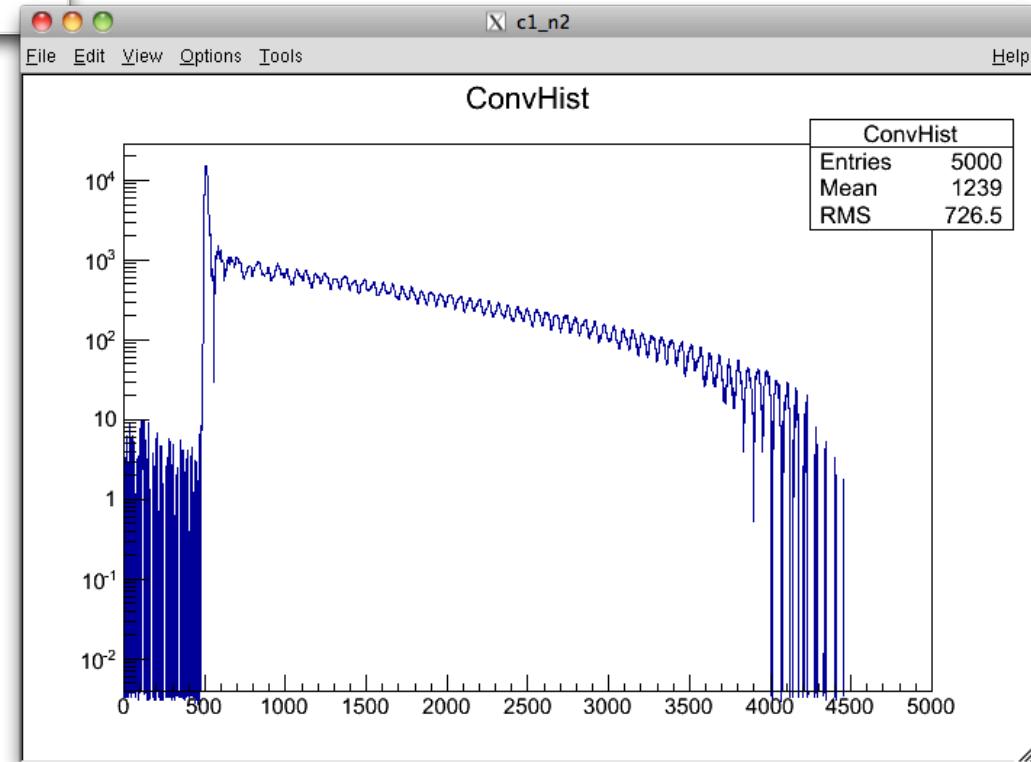
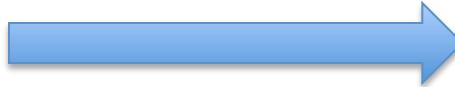
Understanding the effects of Fourier space biases

- We build a toy model to answer two questions:
 - 1) Can a biased frequency space treatment turn a 2-exponential shape into a 3-exponential shape?
 - 2) Can a biased frequency space treatment affect the time constants extracted from a “real” 3 component superposition?
- We prepare “truth” samples by convolving the impulse response with a known function of 2 or 3 superposed exponentials, around our best fit points.
- Then we use an independently measured impulse response to deconvolve and see what we find.



Can we turn a 2 component function into a 3 component function with naïve deconvolution?

Convolve with 1PE + add random noise





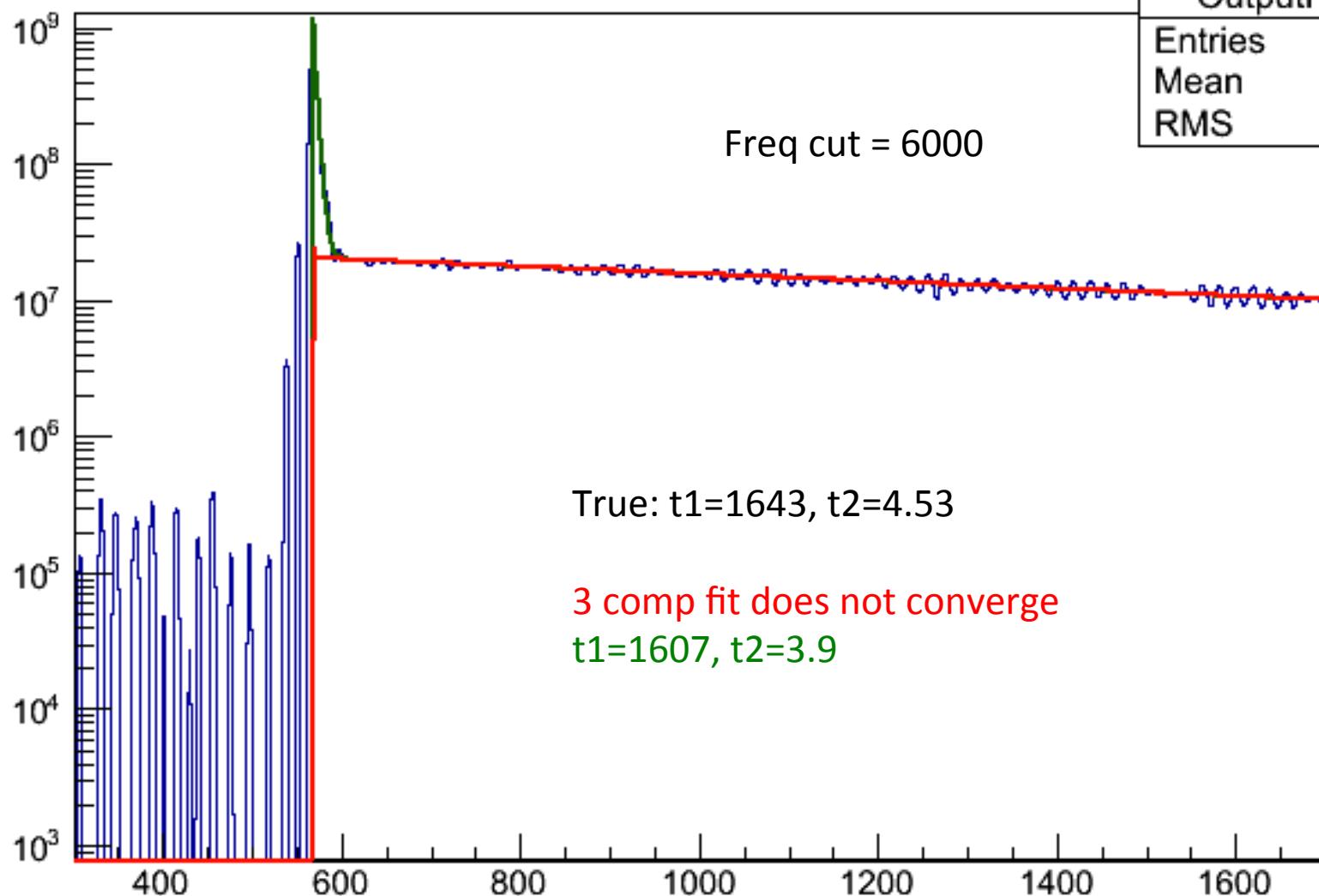
X c1_n11

File Edit View Options Tools

Help

OutputPulse

OutputPulse	
Entries	5000
Mean	928.2
RMS	354.1





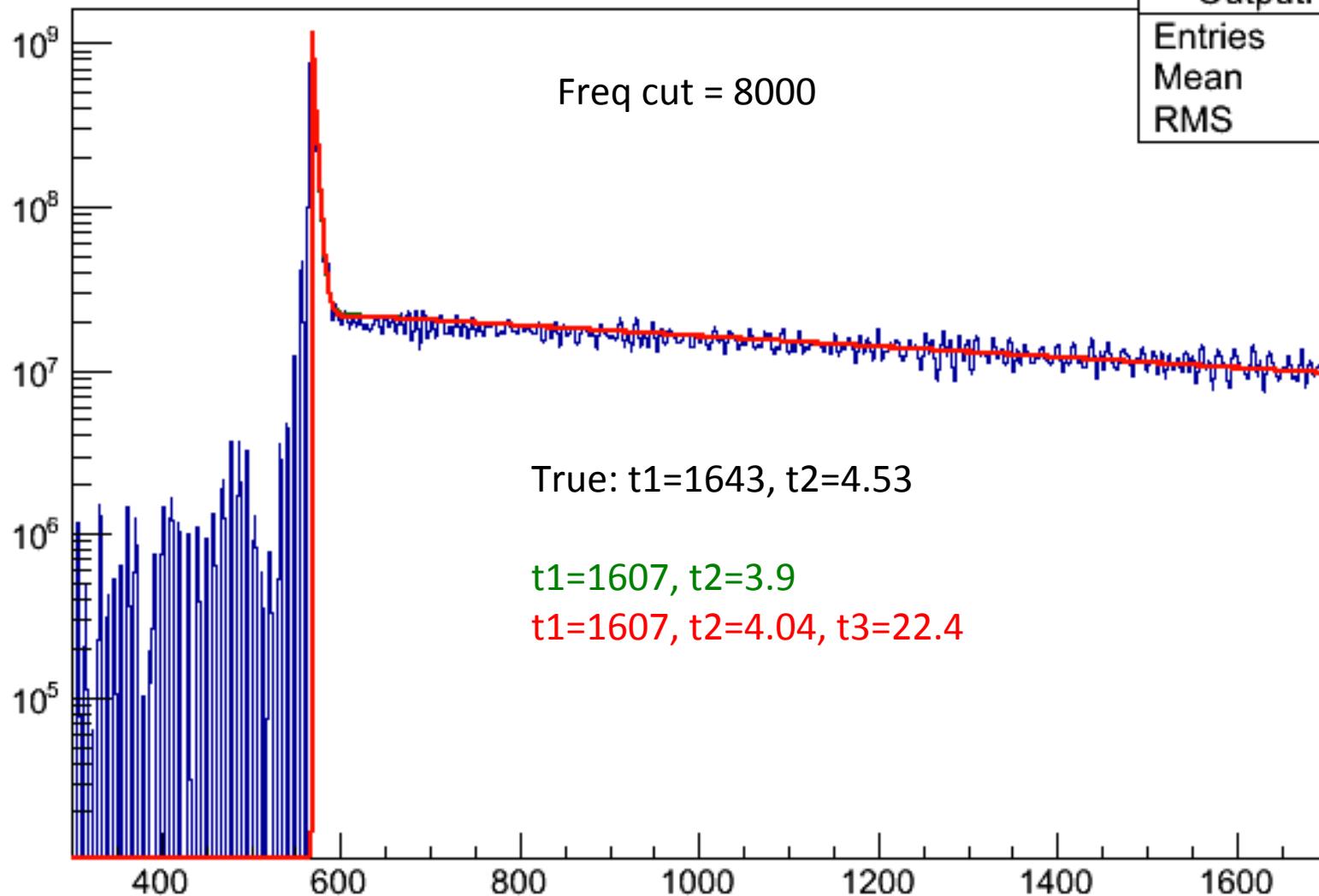
X c1_n8

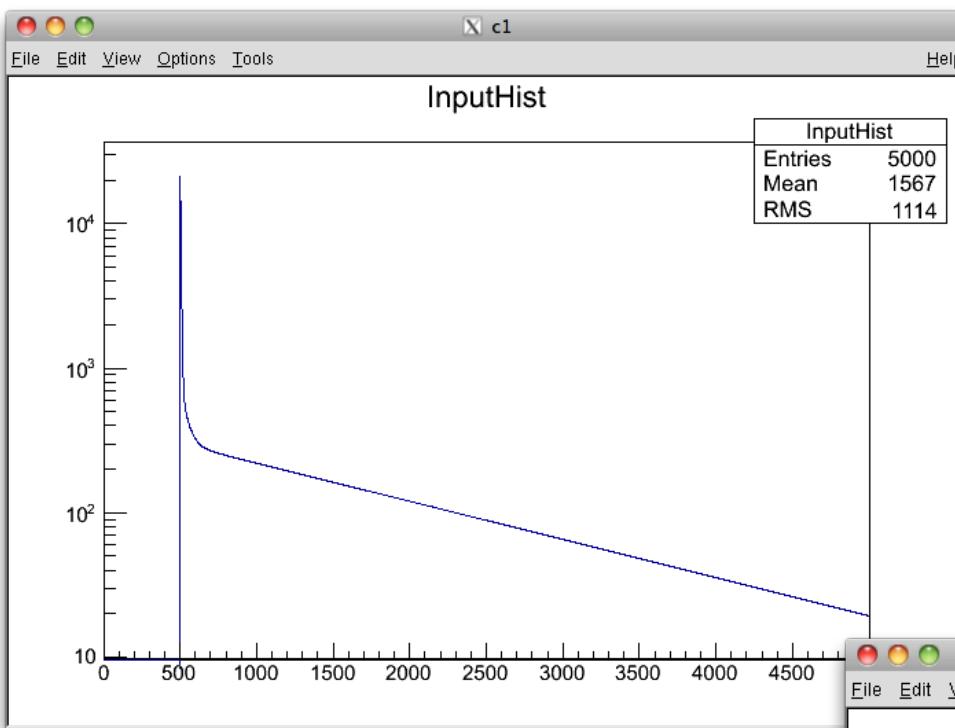
File Edit View Options Tools

Help

OutputPulse

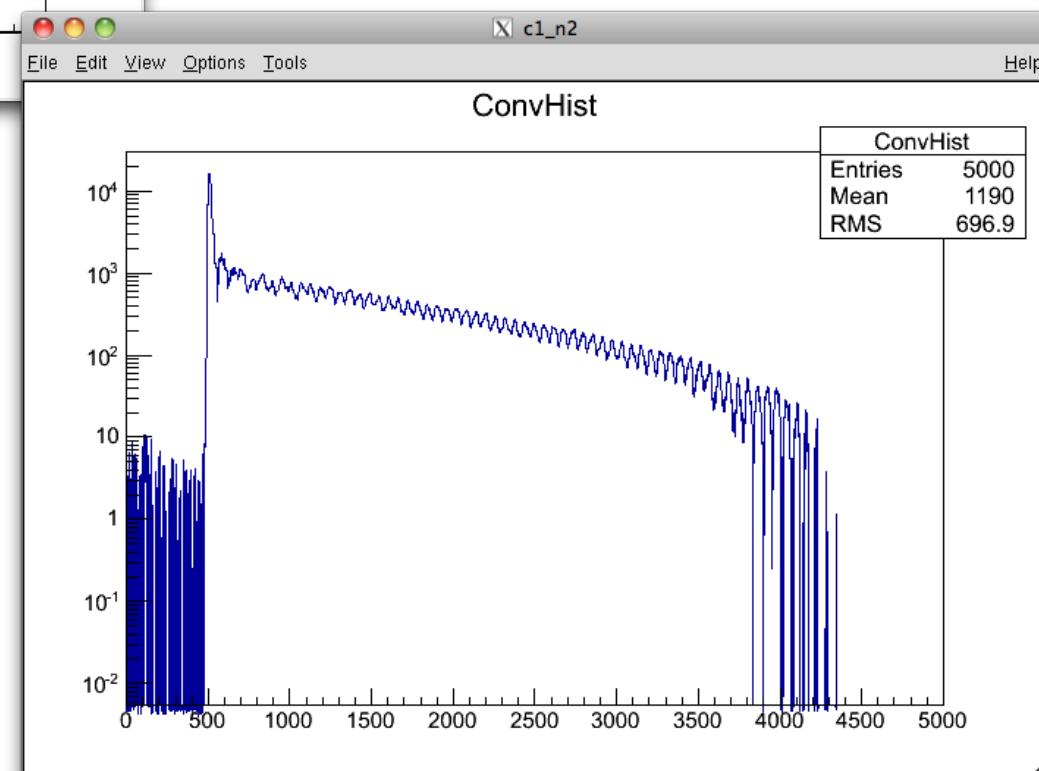
OutputPulse	
Entries	5000
Mean	928.2
RMS	354





Can we destabilize a 3 exponential fit with a naïve deconvolution?

Convolve with 1PE + add random noise

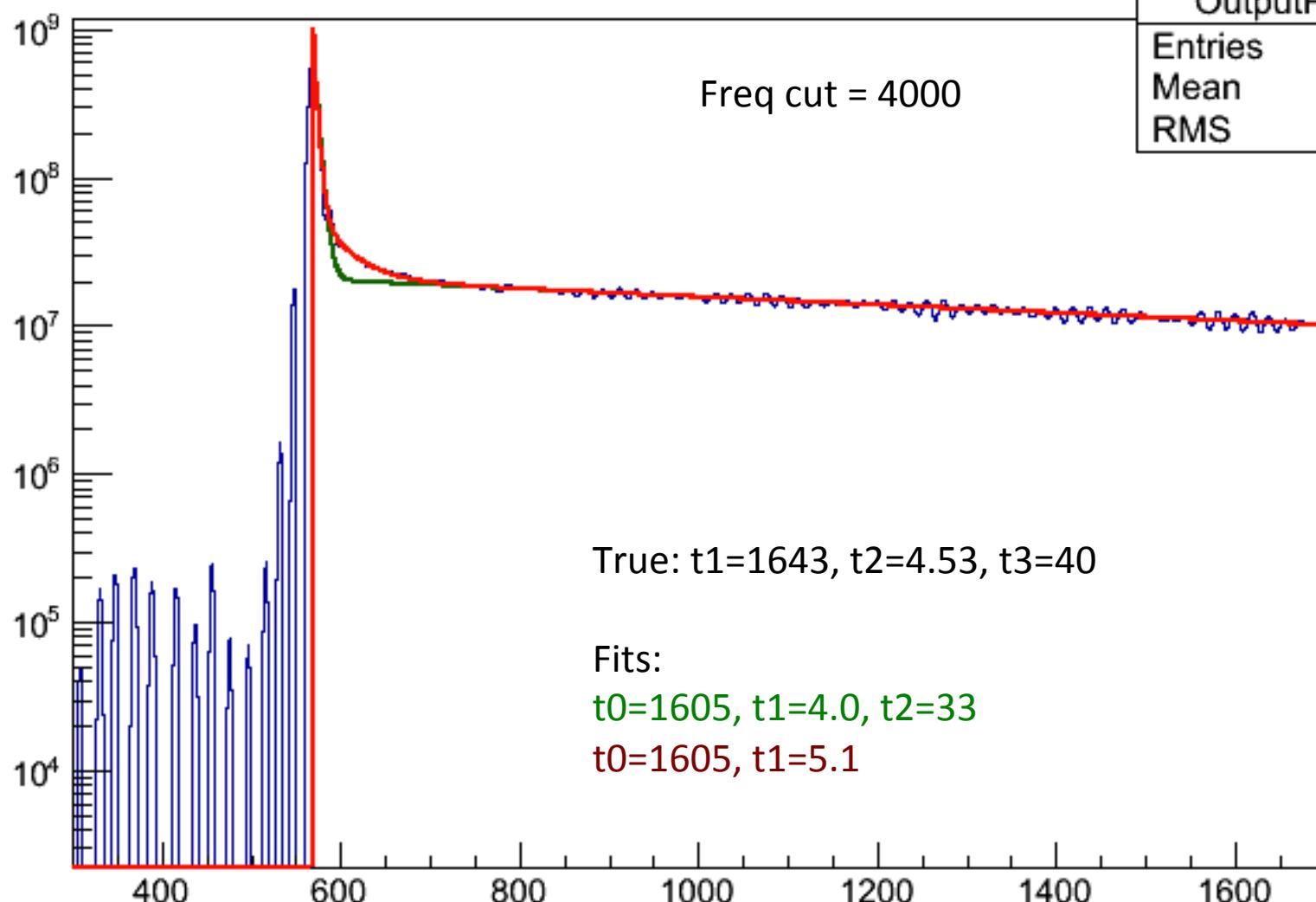




X c1_n3

[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse

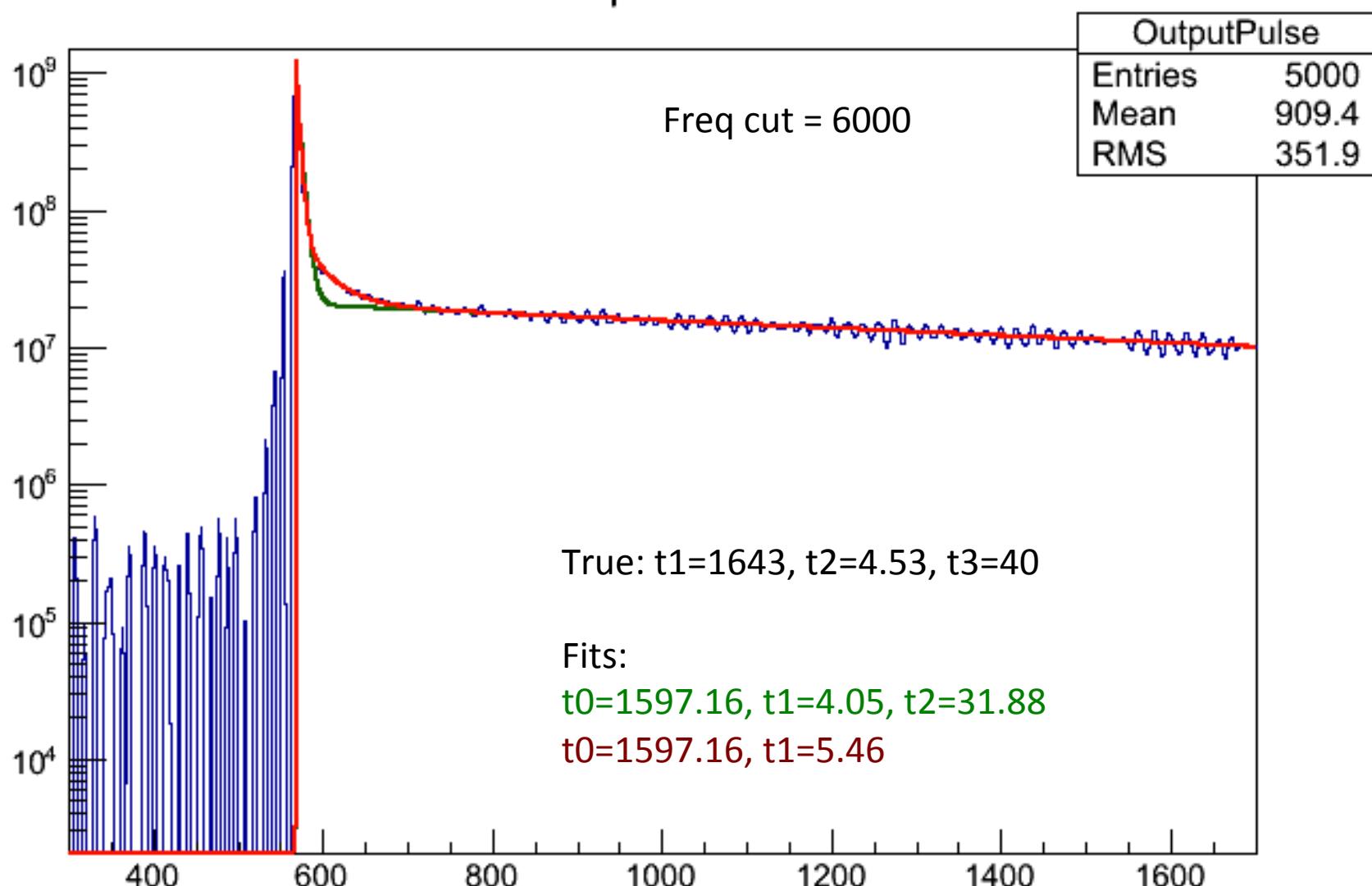




X c1_n8

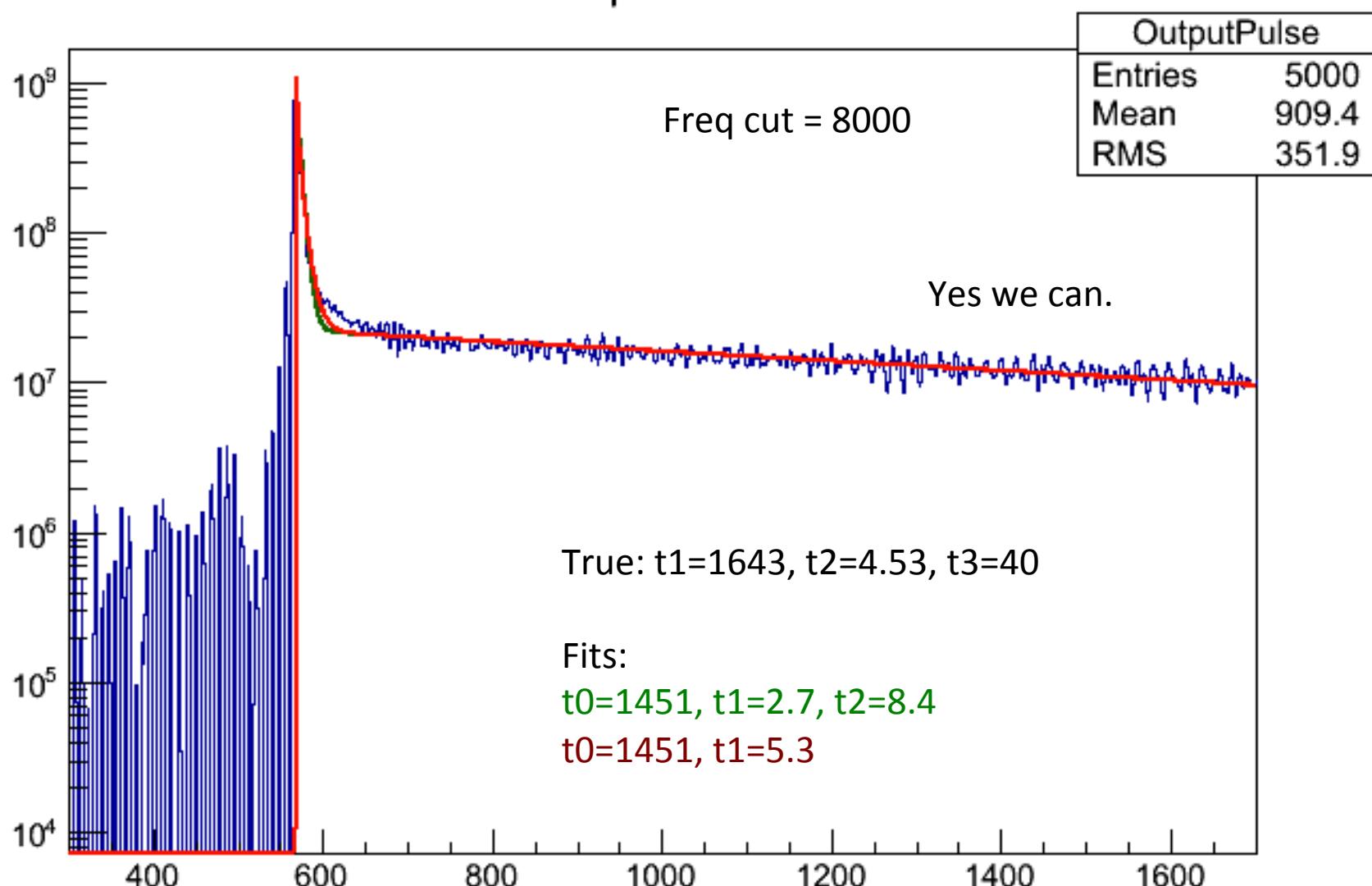
[File](#) [Edit](#) [View](#) [Options](#) [Tools](#)[Help](#)

OutputPulse





OutputPulse



Summary

- Deconvolution necessarily involves a high frequency cutoff of some form.
- We can trade off noise rejection against signal shape preservation, but there is no obvious optimal point
- From talking to signal processing experts, we have come to the conclusion that there is no way to deconvolve away the 1PE shape and not introduce a shape bias. However, it seems unlikely that the cut is responsible for the intermediate component.
- WArP use similar deconvolution methods but have few technical details in their paper. We have the reference the cite, which also gives no recommendation on this issue.
- It is likely they also suffer from some manifestation of this problem.

Backup Slides



X c1

File Edit View Options Tools

Help

CorrHist

